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THEORETICAL FEASIBILITY OF DIGITAL COMMUNICATION OVER OCEAN AREAS BY HIGH FREQUENCY RADIO

LEVEL II

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16. Abstract

The theoretical reliability of digital data transmission via high-frequency radio is examined for typical air traffic routes in the Atlantic and Pacific areas to assist the U.S. Department of Transportation in the evaluation of a system for improving air traffic control over ocean areas. The expected performance of a reference high-frequency data transmission system of 1200 bits per second with a permissible error rate of one in a thousand binary error is expressed as a percentage of time that a given theoretical reliability will be equaled or exceeded.

The expected performance of air-to-air HF systems is also considered, and it is concluded that these systems should work for the reference communication system out to the line-of-sight range of about 800 km for high-flying aircraft.

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Preface

As part of the increasing concern to improve air traffic control of oceanic regions, the Department of Transportation's Transportation Systems Center is investigating various methods to effect such improvement. One such method involves the use of HF data transmissions between aircraft and ground stations.

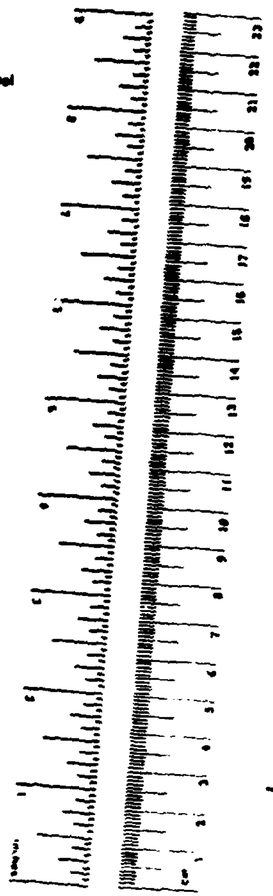
The report presented herein was prepared by the Institute for Telecommunication Sciences. It is one of two reports describing the potential usefulness of HF data transmissions for oceanic ATC improvement.

This report was completed under the direction of TSC Program Manager, Leslie Klein.

METRIC CONVERSION FACTORS

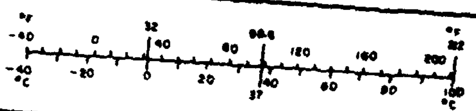
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

At the present time an international group is considering the future communications system for oceanic air traffic control (ATC). This group is examining a range of technical solutions including improvement of the present high frequency (HF) radio system, satellites, air-to-air relay, and other technical approaches which show promise of satisfying future aeronautical communications requirements for oceanic ATC.

As a participant in this international activity, the U.S. Department of Transportation is examining the potential of the present HF radio system to carry digital data communications with high reliability and with low bit and message error rates. To assist in the evaluation of such a system, it appears that theoretical studies are required to answer the following questions:

1) What is the theoretical reliability of digital data transmission via HF radio?
2) How does this reliability vary with data rates?
3) What are typical HF ground wave ranges between aircraft?
4) How may these ranges be expected to vary with time, season, and geographic location?
5) How useful are sounders or other techniques to assist in channel selection?
6) What improvement in reliability can be expected if modern coding is used?

2. ASSUMPTIONS

The theoretical feasibility of digital communication over ocean areas may be estimated from a sample of two areas: (1) the North Atlantic and (2) the Pacific. The North Atlantic area is of particular interest. Since high frequency skywave communication can be expected to be better in most other areas, the theoretical reliability of digital systems in the North Atlantic should be exceeded in most other ocean areas.

A satisfactory reference data rate requirement for Air Traffic Control (ATC) is 1200 bits per second. Theoretical system reliability at other data rates is needed as part of this study. The basic uncorrected permissible bit error rate is 10^{-3}. Reliability as a function of error rate is required.

There will be a continuing requirement of oceanic ATC via HF radio. Time sample periods to estimate the long term reliability may be taken as:

four seasons (March, June, September, and December); and

three solar activity levels (twelve-month average Zurich sunspot numbers of 10, 60, and 110).

Dividing of the currently authorized frequencies for the Major World Air Route Area into nine groups (3.0, 3.5, 4.7, 5.6, 6.6, 8.9, 11.3, 13.3, and 18.0 MHz) will approximate the propagation characteristics.

The diurnal variation of system reliability may be estimated by computation at each even hour of Greenwich Mean Time (GMT).

Aircraft equipment can be represented by antennas with 0 dB gain relative to an isotropic antenna, and aircraft transmitters will operate at 400 watts.

Ground station antennas will have a 6 dB gain relative to an isotropic antenna.

The aircraft-to-ground link is normally weaker than the ground-to-aircraft link. System performance computations based on the aircraft-to-ground link will provide an adequate estimate of the overall reliability of the system.

The frequency selection capability will be such that the best of the available frequencies will be used at all times.

The ground station will be in a man-made noise area typical of rural man-made noise as defined by the International Radio Consultative Committee (CCIR); i.e., -148 dBW in one hertz bandwidth at 3 MHz.

The study will involve two ground stations for each area: New York City and Shannon, Ireland, for the North Atlantic, and San Francisco and Honolulu for the North Pacific. If more ground stations were available, the reliability would be expected to improve. The system reliability will be the better of the reliabilities to the ground stations.

Aircraft locations will be sampled at 200 km from the ground terminals and at 500 km intervals along the great circle path between the ground terminals.

3. FACTS BEARING ON THE PROBLEM

Techniques for predicting the performance of skywave communication systems have been available for many years (CRPL, 1948; Laitinen and Haydon, 1962; Haydon and Lucas, 1966). Recent experience in predicting the performance of over-the-horizon radars have permitted an improvement in these predictions (J. Lloyd, Private Communications).

Predicting the performance of skywave systems involves a representation of the ionosphere with geographic and time variations of each of the regions (Leftin, 1976; CCIR, 1966). The degree of ionization in the various regions determines whether a radio frequency will be propagated via the skywave, defines the path of the propagation, and permits an estimate of the losses involved in the propagation process. When ionospheric characteristics are combined with equipment characteristics (i.e., transmitter power, antenna gain patterns, etc.), it is possible to estimate the signal power that is expected to be available at the receiver terminals. This available power has marked variability, depending not only upon path length but also upon frequency, time of day, season of year, and solar activity level. After the best available estimates of the influence of these factors have been made, the resultant available signal power still needs to be expressed statistically. Normally in high-frequency, skywave predictions, this statistical expression is divided into two parts: (1) the short-term variations of the signal, i.e., minute-to-minute fading with the hour, and (2) a longer term variation, the variation of hourly median signal levels from day-to-day at a given hour within the month.

The short term (minute-to-minute) variation is often adequately described by the Rayleigh distribution (a combination of an infinite number of vectors of random phase and amplitude), while the day-to-day variation has been empirically determined and is estimated as a function of path length, geographic location and time.

The statistical description of the available signal power needs to be combined with a statistical description of the expected noise power to obtain an estimate of the available signal-to-noise ratio. The expected noise power is a combination of atmospheric noise and cosmic noise levels (CCIR, 1964), and man-made noise (CCIR, 1975). This combination involves median and upper and lower deciles of each noise source. The resultant noise level has a frequency, geographic, and time variation similar to the available signal levels.

The short term (e.g., minute-to-minute or less) variations of the signal and the noise, as well as the relative magnitude of the signal-to-noise with short term periods, are normally associated with the quality of the signal (e.g., error rates for digital systems), while the long term variations (day-to-day) are associated with the reliability of the circuit, i.e., the percentage of days within the month that a specified quality may be expected to be equaled or exceeded.

After the long term distribution of the available signal-to-noise ratio has been estimated (at a given hour, season, solar activity level, frequency, equipment availability, and path length), it is necessary to enter this distribution with a required signal-to-noise ratio to estimate the system reliability (Lucas and Haydon, 1966).

The required signal-to-noise ratio will depend not only upon the type of service involved (e.g., voice or teletype), but also upon the transmission speed and permissible error rates.

4. DISCUSSION

4.1 BASIC SKYWAVE RADIO PROPAGATION PREDICTIONS

When the assumptions made in Section 2 are combined with the techniques discussed in Section 3, a prediction of the expected reliability of a skywave system is possible. Table 1 is a sample of the computer output used in

estimating reliability for this report. Table 1 may be described as follows: The first line gives the particular method of the prediction model used--Method 23 of the latest Institute for Telecommunication Sciences' HF Prediction Model (IONCAP 78.03)--the page number is the numerical sequence of the sample chosen for this illustration. The second line gives the month and the solar activity level for which the prediction applies (December – low solar activity, i.e., SSN 10). The 1978 date is superfluous. The third and fourth lines indicate the circuit terminals involved: New York (40.67N; 73.83N) toward Shannon to an aircraft location, 43.37N; 68.93N, at an azimuth of 5.155 degrees East of North, the 234.60 degrees is the azimuth of New York relative to the aircraft location. The azimuths are followed by the great circle distance involved, i.e., 270 nautical miles or 500 kilometers. The fifth, sixth, and seventh lines identify the antennas and antenna-gain prediction methods used--a transmitter antenna equivalent to an isotropic radiator (i.e., 0 dB gain) and a receiving antenna with a gain 6 dB above an isotropic antenna. The eighth line shows the transmitter power used (400 watts) and the man-made noise level at the receiving location (-148 dBW at 3 MHz). The man-made noise level at other frequencies is an internal computer calculation from an established frequency dependence of man-made noise. The Req. Rel. = .90 is used only if lowest useful frequency computations are required and is not used in the analysis. The final entry of the eighth line is the required signal-to-noise ratio (hourly median signal-to-hourly average noise density for the reference service requirement: a 10^{-3} bit error rate for a 1200 bit per second dual-filter frequency-shift teletype system). (See Appendix A for a more detailed description of this 57 dB signal-to-noise density requirement.)

The ninth and tenth lines provide the caption for the body of the computer tabulation. The first column is the Universal Time involved (UT); the second column caption shows the classically defined Maximum Useful Frequency (MUF) for the circuit. The balance of the table captions in the tenth line are frequencies representing the high frequency bands available for the Aeronautical Mobile Service. All frequencies are in megahertz.

The right hand stubs for the table describe the entries in the body of the table. The first stub (FREQ) identifies the column captions for the table. The second line designates the dominant propagation mode; i.e., one hop via the

E layer (1E), one hop via the Sporadic-E layer (1ES), one hop via the F2 region (1F2), etc. The third line is the expected signal level of the receiver input, the monthly median of the hourly median signal in decibels relative to one watt. The fourth line is a combination of the atmospheric, man-made, and cosmic noise levels expressed as monthly medians of hourly median noise density (dB relative to one watt for a one-hertz bandwidth). The fifth line is the monthly median of the hourly median signal-to-noise density ratio. The sixth line is an estimate of the number of days within the month that the required signal-to-noise (S/N) ratio will be equaled or exceeded. This is the circuit reliability, the system parameter of primary interest in this analysis. The remaining lines, SIG LW, SIG UP, SNR LW, and SNR UP, are measures of expected signal and signal-to-noise ratio distribution (i.e., the dB distances to the upper and lower deciles of the signal and the signal-to-noise ratio).

As noted above, the circuit reliability is of principal interest in the study. It should be noted that this reliability depends markedly upon the operating frequency and that in Table 1 for the times shown (night) the aeronautical bands of 3.0 and 3.5 MHz are the most reliable. Table 2 is the same as Table 1 except for a different time (late afternoon). Note that the optimum communication channels have changed from 3.0 and 3.5 MHz to higher channels and that the optimum frequencies are rapidly changing with time. Table 3 is for the same time period as Table 2 but for a greater distance. Note that optimum frequencies change markedly with distance as well as with time of day. Figure 1 shows the diurnal variation of circuit reliability for those aeronautical bands with reliability greater than 40 percent at a distance of 500 kilometers. Note that, to maintain a high circuit reliability, it is necessary to change frequency. At some times, several frequencies have a high reliability, while at other times there is only one. Figure 5 is similar to Figure 1 except that the diurnal variation at a distance of 1500 kilometers is shown. Note that, although the frequencies with the higher reliability are different, the necessity for frequency changes is similar to that shown in Figure 1. Optimum frequencies depend not only upon distance and time of day, but also upon season and solar activity. Figure 3 illustrates this inter-relationship as a function of the time of day and season of the year.

Table 1. SAMPLE COMPUTER OUTPUT SHOWING THE THEORETICAL RELIABILITY OF A SKYWAVE COMMUNICATIONS SYSTEM IN THE NORTH ATLANTIC DISTANCE 500 km - DECEMBER - LOW SOLAR ACTIVITY (UT = 02, 04, 06, 08)

```
                                 METHOD 23   IONCAP 78.03   PAGE 103

          DEC   ,1978            SSN =   10.
NEW YORK TO SHANNON                                AZIMUTHS          N. MI.       KM
40.67 N    73.83 W - 43.37 N     68.98 W           51.55  234.80     270.2      500.4
                                 MINIMUM ANGLE      .0  DEGREES
ITS- 1 ANTENNA PACKAGE
XMTR    2.0   TO   30.0   CONST. GAIN   H     0.00 L     0.00 A     0.0  OFF AZ     0.0
RCVR    2.0   TO   30.0   CONST. GAIN   H     0.00 L     0.00 A     0.0  OFF AZ     6.0
POWER =      .400 KW   3 MHZ NCISE = -148.0 DBW    REQ. REL = .90  REQ. SNR = 57.0

 UT   MUF

2.0   3.5   3.0   3.5   4.7   5.6   6.6   8.9  11.3  13.3  18.0   0.0   0.0 FREQ
      1F2   1F2   1F2   1ES   1ES   1ES   1ES   1F2   1F2   1F2    -     -  MODE
      -74   -69   -74   -86   -93  -101  -139  -144  -146  -148    -     -  S DBW
     -148  -146  -148  -151  -153  -155  -159  -163  -165  -169    -     -  N DBW
      74.   77.   74.   65.   60.   53.   20.   18.   19.   21.    -     -  SNR
      .92   .98   .92   .76   .60   .42   .02   .00   .00   .00    -     -  REL
      13.   10.   13.   12.   13.   16.   10.    7.    7.    7.    -     -  SIG LW
       4.    2.    4.   10.   13.   20.   22.    1.    1.    1.    -     -  SIG UP
      15.   12.   15.   14.   14.   17.   12.   10.   10.   10.    -     -  SNR LW
      10.    9.   10.   14.   16.   22.   23.    9.    9.    9.    -     -  SNR UP

4.0   3.3   3.0   3.5   4.7   5.6   6.6   8.9  11.3  13.3  18.0   0.0   0.0 FREQ
      1F2   1F2   1F2   1ES   1ES   1ES   1F2   1F2   1F2   1F2    -     -  MODE
      -73   -70   -75   -88   -95  -106  -141  -144  -145  -148    -     -  S DBW
     -147  -146  -147  -151  -153  -155  -159  -163  -165  -169    -     -  N DBW
      73.   76.   72.   62.   57.   49.   17.   19.   20.   21.    -     -  SNR
      .91   .96   .88   .69   .51   .35   .00   .00   .00   .00    -     -  REL
      14.   12.   14.   12.   13.   16.    9.    9.    9.    9.    -     -  SIG LW
       4.    2.    5.   11.   16.   25.    4.    1.    1.    1.    -     -  SIG UP
      16.   14.   16.   14.   15.   18.   11.   11.   11.   11.    -     -  SNR LW
      10.    9.   10.   14.   19.   26.    9.    9.    9.    9.    -     -  SNR UP

6.0   3.8   3.0   3.5   4.7   5.6   6.6   8.9  11.3  13.3  18.0   0.0   0.0 FREQ
      1F2   1F2   1F2   1F2   1ES   1ES   1F2   1F2   1F2   1F2    -     -  MODE
      -79   -73   -76   -89  -103  -119  -148  -150  -151  -154    -     -  S DBW
     -148  -146  -147  -151  -153  -155  -160  -163  -165  -169    -     -  N DBW
      68.   72.   71.   61.   50.   36.   12.   14.   14.   15.    -     -  SNR
      .91   .99   .97   .65   .35   .15   .00   .00   .00   .00    -     -  REL
       8.    3.    6.   12.   12.   17.    2.    2.    2.    2.    -     -  SIG LW
       8.    4.    5.   13.   22.   25.    4.    4.    4.    4.    -     -  SIG UP
      11.    8.    9.   14.   14.   19.    7.    7.    7.    7.    -     -  SNR LW
      11.   10.   10.   16.   23.   26.    9.    9.    9.    9.    -     -  SNR UP

8.0   4.1   3.0   3.5   4.7   5.6   6.6   8.9  11.3  13.3  18.0   0.0   0.0 FREQ
      1F2   1F2   1F2   1F2   1F2   1ES   1F2   1F2   1F2   1F2    -     -  MODE
      -80   -74   -75   -87  -102  -121  -148  -150  -151  -154    -     -  S DBW
     -149  -146  -148  -151  -153  -155  -160  -163  -165  -169    -     -  N DBW
      69.   72.   72.   64.   51.   34.   12.   13.   14.   15.    -     -  SNR
      .88   .99   .99   .63   .36   .13   .00   .00   .00   .00    -     -  REL
      11.    3.    5.   16.   20.   23.    2.    2.    2.    2.    -     -  SIG LW
       7.    5.    5.   12.   21.   25.    4.    4.    4.    4.    -     -  SIG UP
      13.    8.    9.   17.   21.   24.    7.    7.    7.    7.    -     -  SNR LW
      11.   10.   10.   14.   23.   26.    9.    9.    9.    9.    -     -  SNR UP
```

TABLE 2. SAMPLE COMPUTER OUTPUT SHOWING THE THEORETICAL RELIABILITY OF A SKYWAVE COMMUNICATIONS SYSTEM IN THE NORTH ATLANTIC DISTANCE 500 km - DECEMBER - LOW SOLAR ACTIVITY (UT = 18, 20, 22, 24)

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                              METHOD 23   IONCAP 78.03   PAGE 105

          DEC  .1978          SSN =  10.
NEW YORK TO SHANNON                       AZIMUTHS          N. MI.      KM
40.67 N   73.83 W - 43.37 N   68.98 W     51.55  234.80     270.2    500.4
                              MINIMUM ANGLE    .0  DEGREES
ITS- 1 ANTENNA PACKAGE
XMTR   2.0  TO  30.0  CONST. GAIN  H    0.00 L    0.0C A    0.0  OFF AZ    0.0
RCVR   2.0  TO  30.0  CONST. GAIN  H    0.00 L    0.00 A    0.0  OFF AZ    6.0
POWER =    .400 KW  3 MHZ NOISE = -148.0 DBW   REQ. REL = .90  REQ. SNR = 57.0
```

UT	MUF											
18.0	9.1	3.0	3.5	4.7	5.6	6.6	8.9	11.3	13.3	18.0	0.0	0.0 FREQ
	1F2	1 E	1 E	1F1	1F2	1F2	1F2	1F2	1F2	1F2	-	- MODE
	-92	-94	-91	-86	-86	-87	-87	-124	-160	-161	-	- S DBW
	-160	-148	-149	-153	-155	-157	-160	-162	-163	-168	-	- N DBW
	68.	53.	57.	66.	68.	70.	73.	38.	4.	7.	-	- SNR
	.77	.31	.51	.85	.92	.96	.89	.16	.00	.00	-	- REL
	17.	6.	6.	9.	7.	6.	15.	25.	6.	6.	-	- SIG LW
	8.	5.	5.	6.	7.	5.	7.	23.	18.	5.	-	- SIG UP
	19.	9.	10.	11.	10.	9.	17.	26.	9.	9.	-	- SNR LW
	12.	10.	10.	11.	11.	10.	11.	25.	20.	10.	-	- SNR UP
20.0	8.1	3.0	3.5	4.7	5.6	6.6	8.9	11.3	13.3	18.0	0.0	0.0 FREQ
	1F2	1 E	1F2	1F2	1F2	1F2	1F2	1F2	1F2	1F2	-	- MODE
	-90	-80	-80	-82	-83	-83	-98	-150	-158	-160	-	- S DBW
	-159	-147	-149	-153	-155	-157	-160	-162	-164	-168	-	- N DBW
	69.	67.	69.	70.	71.	72.	62.	12.	6.	8.	-	- SNR
	.83	.93	.96	.97	.98	.99	.61	.02	.00	.00	-	- REL
	14.	5.	5.	5.	5.	5.	21.	12.	5.	5.	-	- SIG LW
	8.	6.	6.	5.	5.	5.	13.	25.	5.	5.	-	- SIG UP
	16.	8.	9.	9.	9.	9.	22.	14.	8.	8.	-	- SNR LW
	12.	11.	11.	10.	10.	10.	16.	26.	10.	10.	-	- SNR UP
22.0	6.3	3.0	3.5	4.7	5.6	6.6	8.9	11.3	13.3	18.0	0.0	0.0 FREQ
	1F2	1F2	1F2	1F2	1F2	1F2	1F2	1F2	1F2	1F2	-	- MODE
	-85	-77	-78	-79	-80	-89	-152	-155	-156	-159	-	- S DBW
	-156	-147	-149	-153	-154	-156	-159	-162	-164	-169	-	- N DBW
	69.	70.	71.	73.	73.	66.	8.	7.	8.	10.	-	- SNR
	.90	.39	.99	1.00	1.00	.77	.01	.00	.00	.00	-	- REL
	10.	1.	0.	1.	2.	14.	3.	1.	1.	1.	-	- SIG LW
	8.	5.	5.	5.	5.	10.	24.	4.	4.	4.	-	- SIG UP
	12.	7.	7.	7.	8.	15.	7.	7.	7.	7.	-	- SNR LW
	12.	10.	10.	10.	10.	13.	26.	10.	10.	10.	-	- SNR UP
24.0	4.3	3.0	3.5	4.7	5.6	6.6	8.9	11.3	13.3	18.0	0.0	0.0 FREQ
	1F2	1F2	1F2	1F2	1F2	1ES	1F2	1F2	1F2	1F2	-	- MODE
	-80	-74	-75	-83	-94	-108	-147	-151	-152	-155	-	- S DBW
	-151	-147	-149	-152	-154	-156	-159	-162	-165	-169	-	- N DBW
	70.	73.	73.	68.	59.	48.	12.	12.	13.	14.	-	- SNR
	.93	1.00	1.00	.85	.57	.33	.00	.00	.00	.00	-	- REL
	9.	1.	3.	11.	13.	13.	2.	1.	1.	1.	-	- SIG LW
	7.	4.	5.	9.	16.	25.	19.	3.	3.	3.	-	- SIG UP
	11.	7.	8.	13.	15.	15.	7.	7.	7.	7.	-	- SNR LW
	12.	10.	10.	13.	14.	26.	21.	9.	9.	9.	-	- SNR UP

TABLE 3. SAMPLE COMPUTER OUTPUT SHOWING THE THEORETICAL RELIABILITY OF A SKYWAVE COMMUNICATIONS SYSTEM IN THE NORTH ATLANTIC DISTANCE 1500 km - DECEMBER - LOW SOLAR ACTIVITY UT = 18, 20, 22, 24,)

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                                       METHOD 23   IONCAP 78.03   PAGE 111

            DEC  ,1978                 SSN =  10.
NEW YORK TO SHANNON                              AZIMUTHS             N. MI.       KM
40.67 N    73.83 W - 48.05 N   57.97 W           51.55  242.70         809.8    1499.7
                                       MINIMUM ANGLE     .0  DEGREES
ITS- 1 ANTENNA PACKAGE
XMTR    2.0  TO   30.0  CONST. GAIN  H     0.00 L     0.00 A     0.0  OFF AZ     0.0
RCVR    2.0  TO   30.0  CONST. GAIN  H     0.00 L     0.00 A     0.0  OFF AZ     6.0
POWER =     .400 KW  3 MHZ NOISE = -148.0 DBW   REQ. REL = .90  REQ. SNR = 57.0
```

UT	MUF												
18.0	16.7	3.0	3.5	4.7	5.6	6.6	8.9	11.3	13.3	18.0	0.0	0.0	FREQ
	1F2	1 E	1ES	1ES	1 E	1 E	1F1	1F2	1F2	1F2	-	-	MODE
	-98	-123	-113	-107	-103	-102	-97	-96	-99	-118	-	-	S DBW
	-167	-148	-149	-153	-155	-157	-160	-162	-163	-168	-	-	N DBW
	68.	24.	36.	46.	51.	55.	63.	66.	64.	50.	-	-	SNR
	.75	.00	.01	.09	.23	.39	.77	.91	.86	.32	-	-	REL
	19.	5.	5.	6.	6.	6.	8.	5.	5.	25.	-	-	SIG LW
	8.	5.	5.	5.	5.	6.	6.	7.	5.	18.	-	-	SIG UP
	21.	9.	9.	9.	9.	9.	10.	9.	9.	26.	-	-	SNR LW
	12.	10.	10.	10.	10.	11.	11.	11.	10.	20.	-	-	SNR UP
20.0	14.2	3.0	3.5	4.7	5.6	6.6	8.9	11.3	13.3	18.0	0.0	0.0	FREQ
	1F2	1 E	1 E	1 E	1 E	1F2	1F2	1F2	1F2	1F2	-	-	MODE
	-97	-101	-97	-95	-94	-93	-95	-96	-96	-171	-	-	S DBW
	-165	-147	-149	-153	-155	-157	-160	-162	-164	-169	-	-	N DBW
	67.	47.	52.	57.	61.	63.	64.	66.	67.	-2.	-	-	SNR
	.74	.10	.27	.51	.75	.83	.86	.91	.90	.00	-	-	REL
	19.	5.	5.	5.	4.	5.	5.	5.	8.	25.	-	-	SIG LW
	10.	6.	6.	6.	6.	6.	6.	6.	7.	25.	-	-	SIG UP
	21.	8.	9.	9.	8.	9.	9.	9.	10.	26.	-	-	SNR LW
	13.	11.	11.	11.	11.	11.	11.	10.	11.	26.	-	-	SNR UP
22.0	10.5	3.0	3.5	4.7	5.6	6.6	8.9	11.3	13.3	18.0	0.0	0.0	FREQ
	1F2	1 E	1 E	1F2	1F2	1F2	1F2	1F2	1ES	1ES	-	-	MODE
	-92	-87	-88	-90	-90	-91	-91	-110	-129	-194	-	-	S DBW
	-162	-147	-149	-152	-154	-156	-160	-163	-165	-169	-	-	N DBW
	69.	60.	61.	62.	64.	65.	67.	52.	36.	-25.	-	-	SNR
	.83	.69	.77	.82	.59	.92	.97	.38	.16	.00	-	-	REL
	14.	0.	1.	1.	1.	1.	1.	18.	18.	24.	-	-	SIG LW
	9.	6.	7.	6.	6.	6.	5.	18.	25.	25.	-	-	SIG UP
	15.	7.	7.	7.	7.	7.	7.	19.	19.	25.	-	-	SNR LW
	12.	11.	11.	11.	11.	11.	10.	20.	26.	26.	-	-	SNR UP
24.0	7.3	3.0	3.5	4.7	5.6	6.6	8.9	11.3	13.3	18.0	0.0	0.0	FREQ
	1F2	1F2	1F2	1F2	1F2	1F2	1ES	1ES	1ES	1ES	-	-	MODE
	-84	-83	-84	-82	-53	-85	-100	-108	-115	-150	-	-	S DBW
	-157	-147	-149	-152	-154	-156	-160	-163	-165	-169	-	-	N DBW
	73.	64.	65.	69.	70.	70.	59.	55.	50.	19.	-	-	SNR
	.85	.84	.90	.97	.96	.90	.58	.43	.32	.03	-	-	REL
	18.	4.	3.	5.	7.	11.	11.	12.	16.	25.	-	-	SIG LW
	6.	4.	5.	2.	1.	3.	11.	12.	18.	25.	-	-	SIG UP
	19.	8.	8.	9.	10.	13.	13.	14.	18.	26.	-	-	SNR LW
	11.	10.	10.	9.	9.	9.	14.	15.	20.	26.	-	-	SNR UP

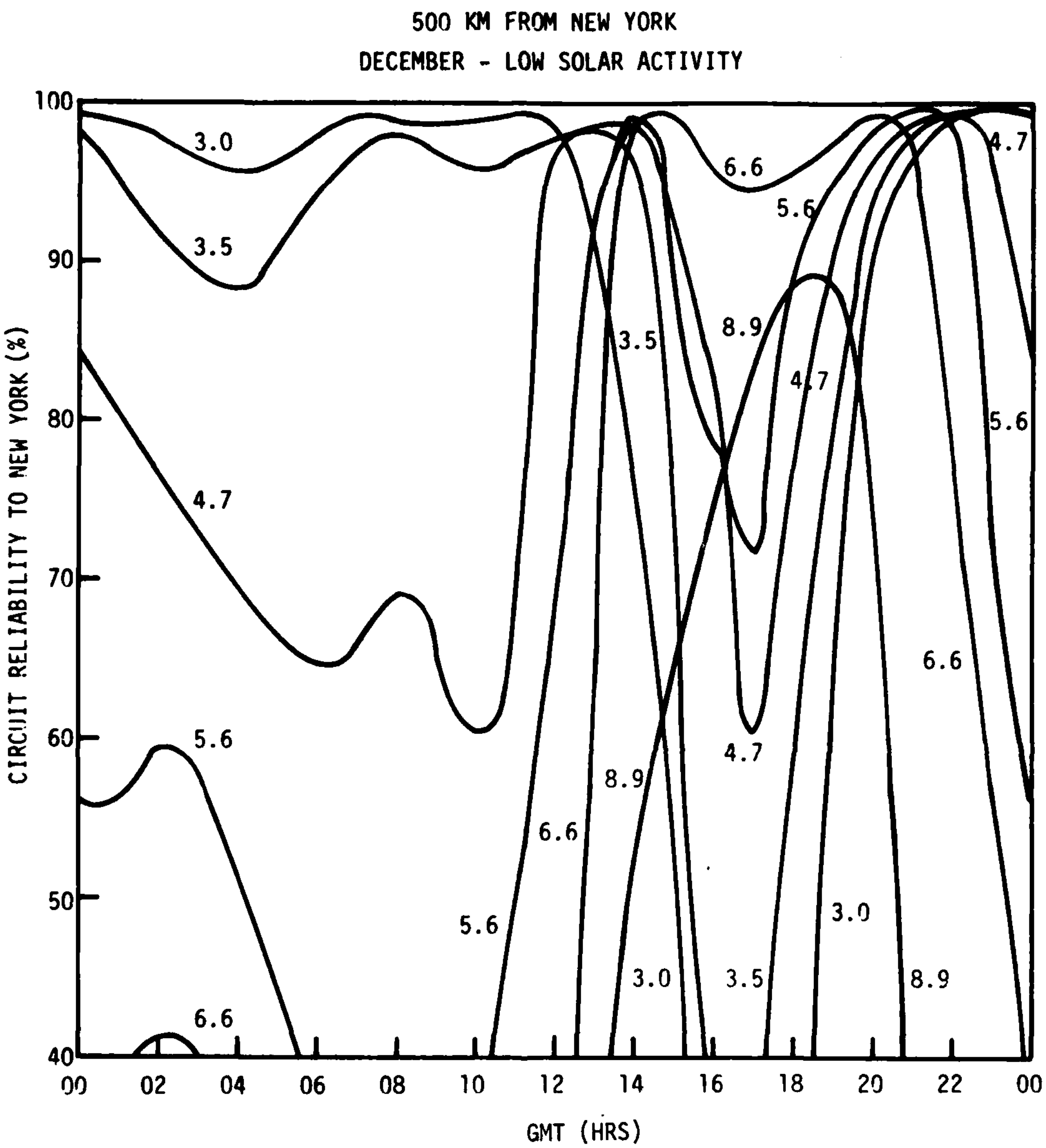


FIGURE 1. SAMPLE CHART SHOWING HOW CHANGING FREQUENCY DURING THE DAY HELPS TO MAINTAIN CIRCUIT RELIABILITY - NORTH ATLANTIC - DISTANCE 500 km

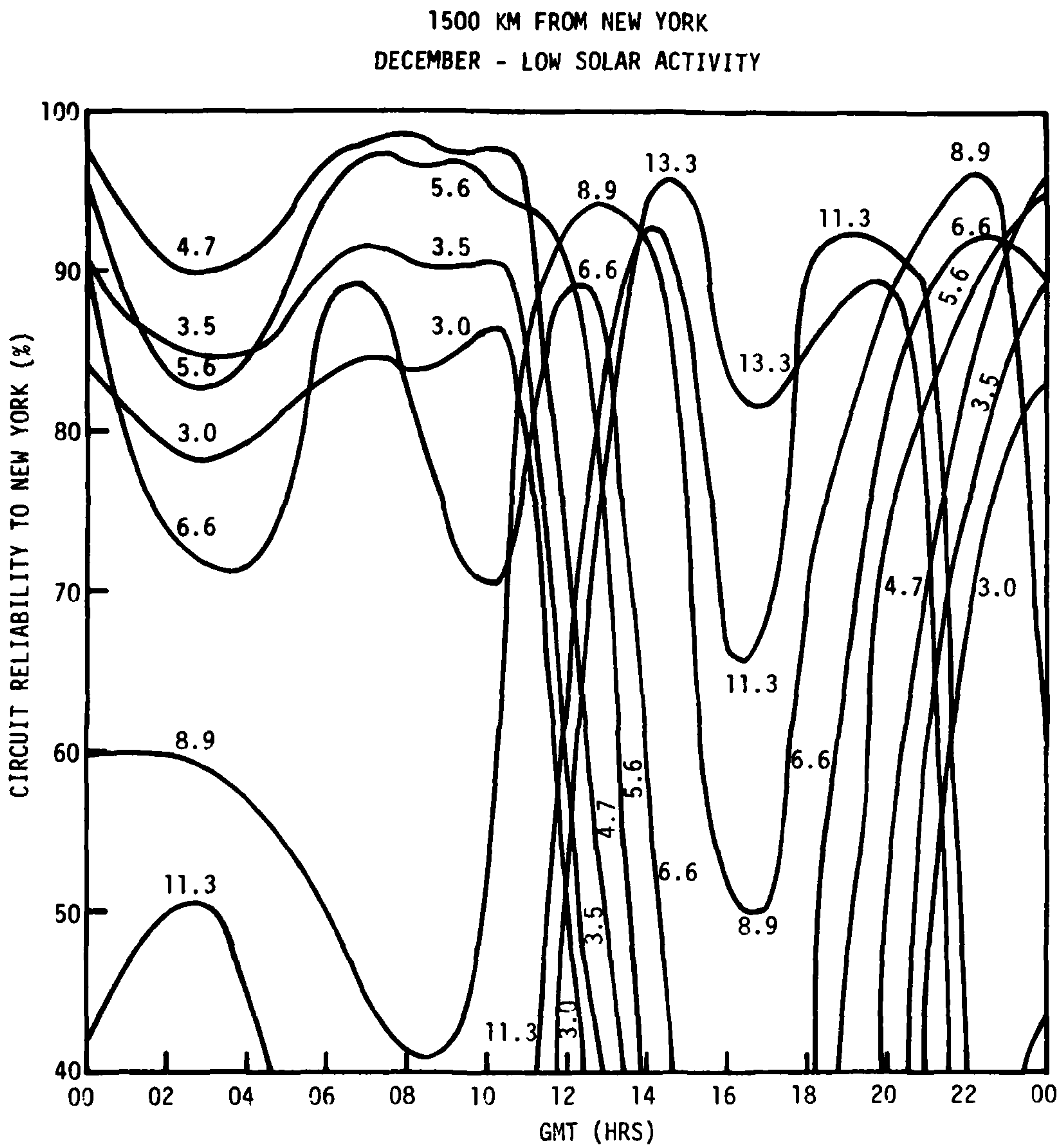


FIGURE 2. SAMPLE CHART SHOWING HOW CHANGING FREQUENCY DURING THE DAY HELPS TO MAINTAIN CIRCUIT RELIABILITY - NORTH ATLANTIC-DISTANCE 1500 km

4.2 DISTANCE DEPENDENCE OF SKYWAVE CIRCUIT RELIABILITY

Generally, system reliability decreases as circuit distance increases, and for long-distance air routes, communication reliability will be better if communication may be to either terminal. Figure 4 shows a sample of the theoretical reliability if operation is on the optimum frequency to either end of the air route and illustrates how communication to either terminal tends to maintain a high reliability over the entire route.

Appendix B is an extract of the more pertinent information from the basic computation. The optimum communication frequency, circuit reliability, and associated terminal are shown for each of the sample locations and sample time used in the analysis. Figure 5 summarizes the North Atlantic data from Appendix B to estimate the overall distance dependence of circuit reliability for the reference service. Percentage of samples (time periods) associated with a specified reliability are shown as a function of distance. Note that the lowest reliability occurs near mid-path and that the theoretical reliability may be as low as 35 percent at this location during some sample period. (According to Appendix B, this time period is established as 1400 GMT, June, high solar activity). Figure 6 summarizes the North Pacific data from Appendix B to estimate distance dependence circuit reliability in the same manner as Figure 5 for the North Atlantic. Note that communication reliability may be expected to be somewhat better in the North Pacific. Figure 7 is designed to estimate the expected reliability of a circuit when the circuit parameters (e.g., tranmitter power, antenna gain, transmission speed, modulation type, tolerable error rated, coding gains, etc.) differ from the reference circuit. Figure 7 is not rigorous, the actual change in the circuit reliability complex being a function of operating frequency, geographic location, etc. Figure 7, however, is considered a useful estimate of the typical change in circuit reliability as the effective system gain of any circuit is known relative to a reference circuit. To use Figure 7, select a circuit reliability of a reference circuit for a situation of interest and determine the effective system gain required to obtain a desired reliability. For example, Figure 5 shows that the theoretical reliability for the North Atlantic may be as low as 35 percent within the sample periods used for the analysis. To use Figure 7, enter the chart with the reliability of the reference circuit (abscissa) and the desired reliability (e.g., 99 percent on the ordinate). Read +20 dB from the body of the chart.

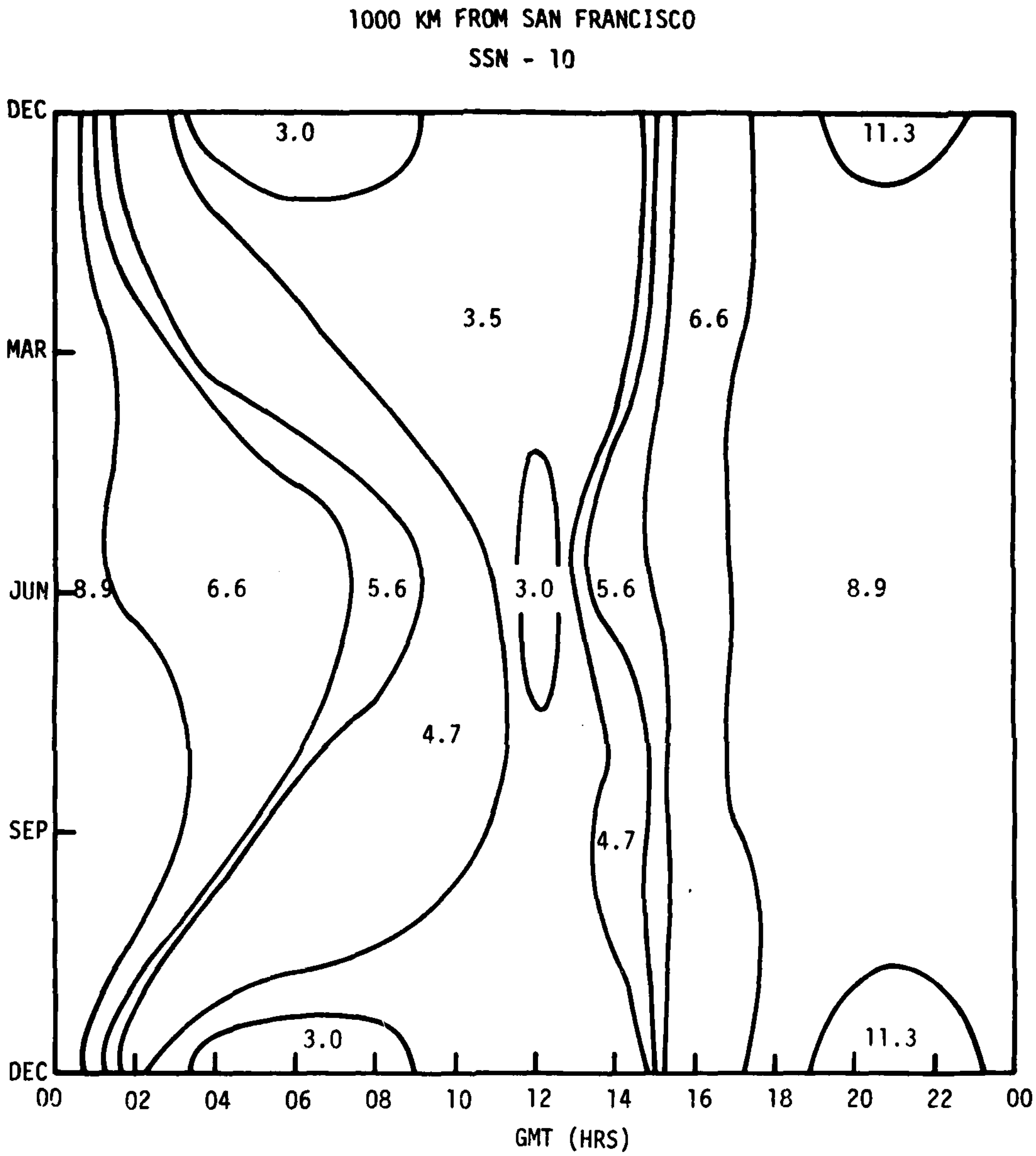


FIGURE 3. CONTOURS OF OPTIMUM FREQUENCY (in MHz) SHOWING HOW SEASONAL AND DIURNAL CHANGES IN FREQUENCY ARE REQUIRED FOR OPERATION

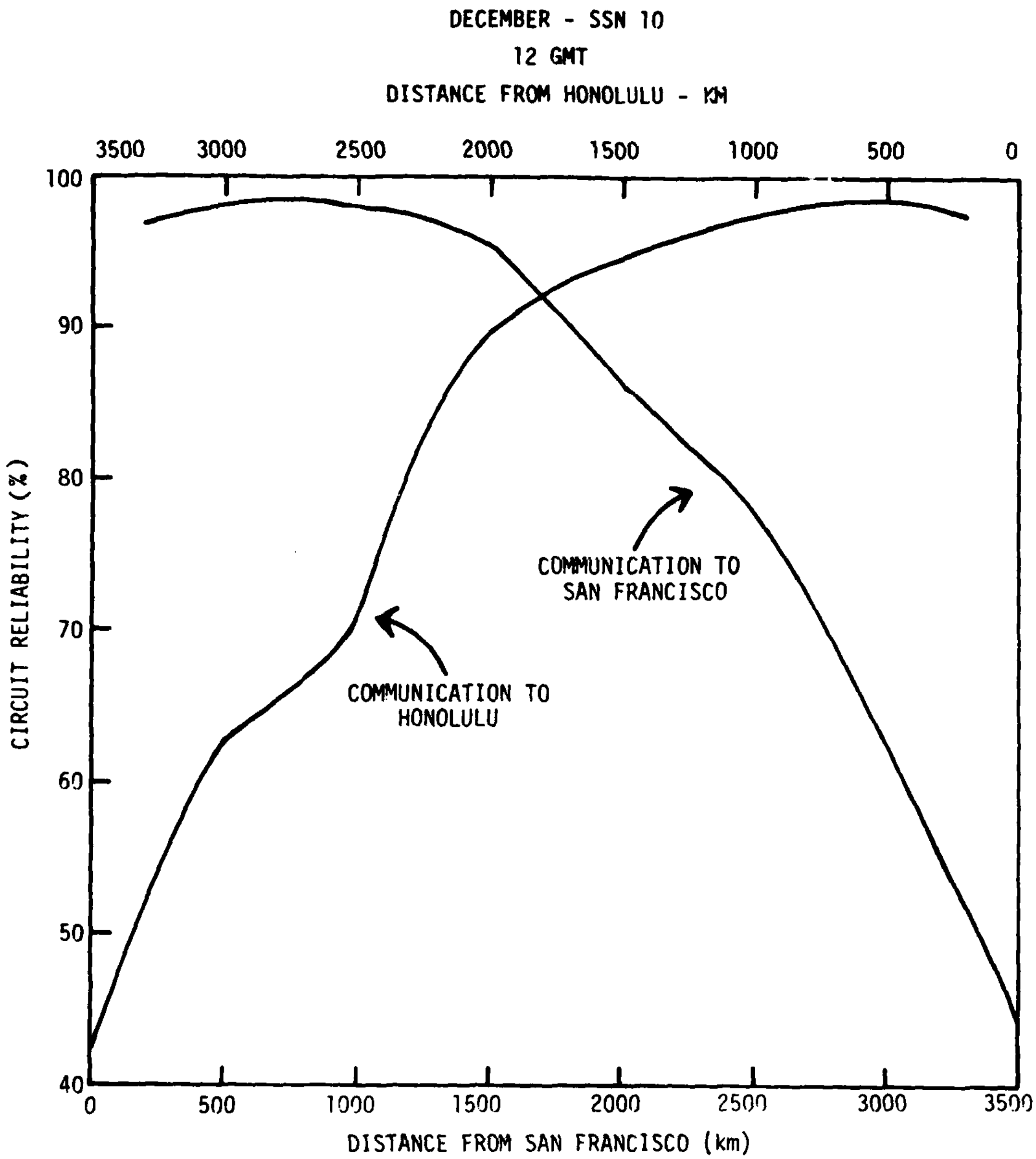


FIGURE 4. SAMPLE CHART SHOWING HOW COMMUNICATION RELIABILITY IS MAINTAINED WHEN SKYWAVE COMMUNICATION MAY BE TO EITHER END OF THE AIR ROUTE

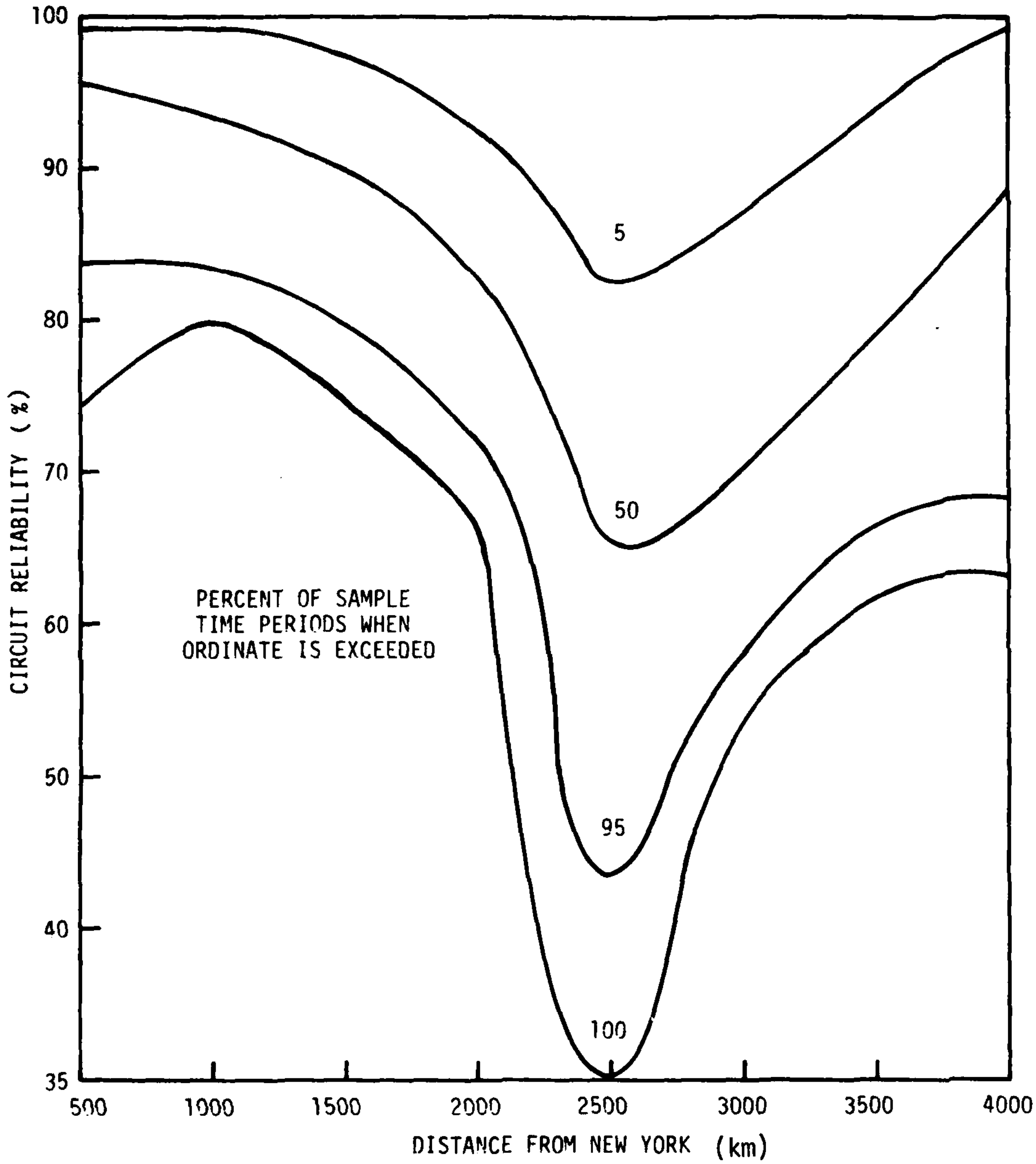


FIGURE 5. OVERALL DISTANCE VARIATION OF THEORETICAL CIRCUIT RELIABILITY - NORTH ATLANTIC AIR ROUTE

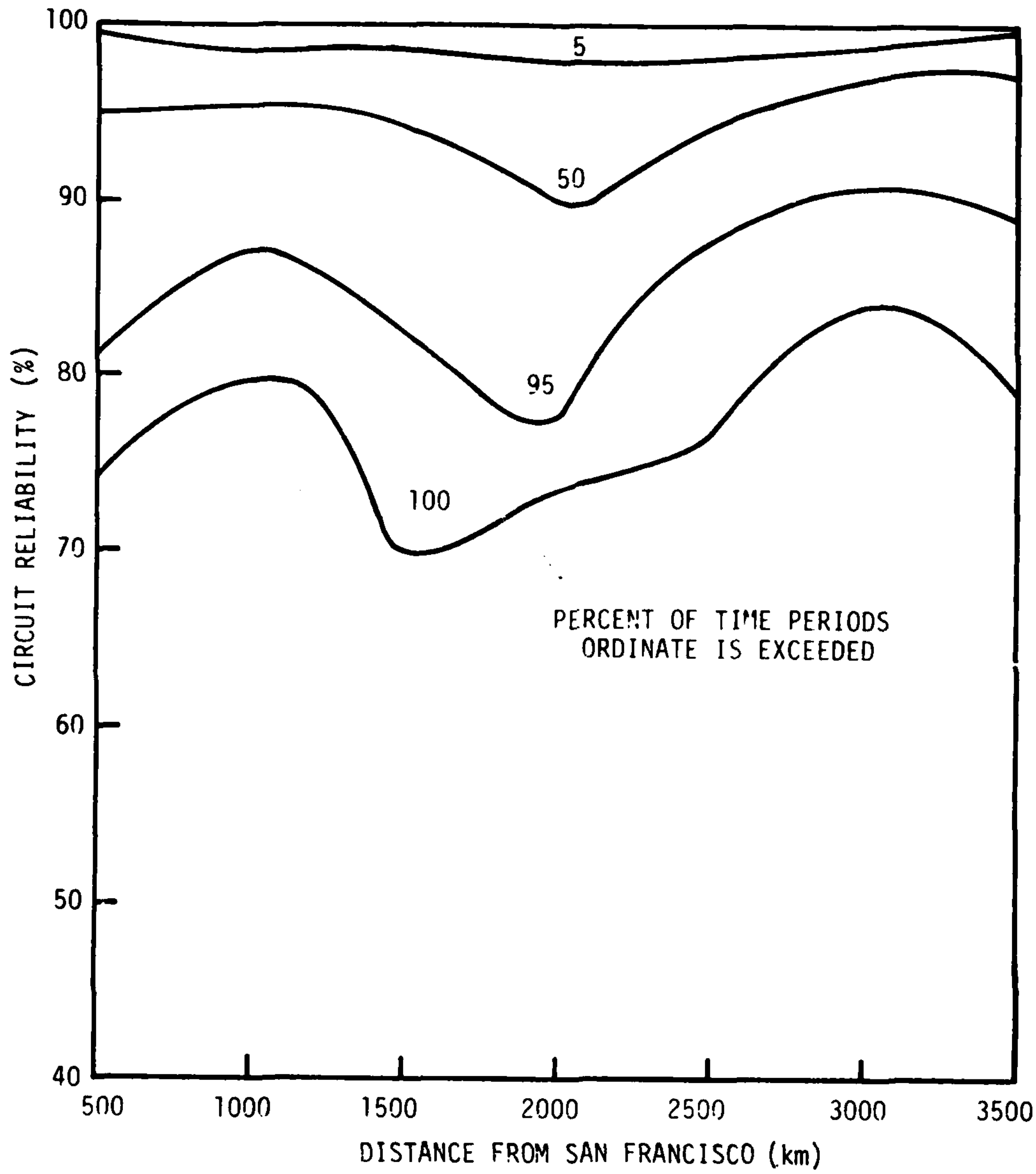


FIGURE 6. OVER DISTANCE VARIATION OF THEORETICAL CIRCUIT RELIABILITY - NORTH PACIFIC AIR ROUTE

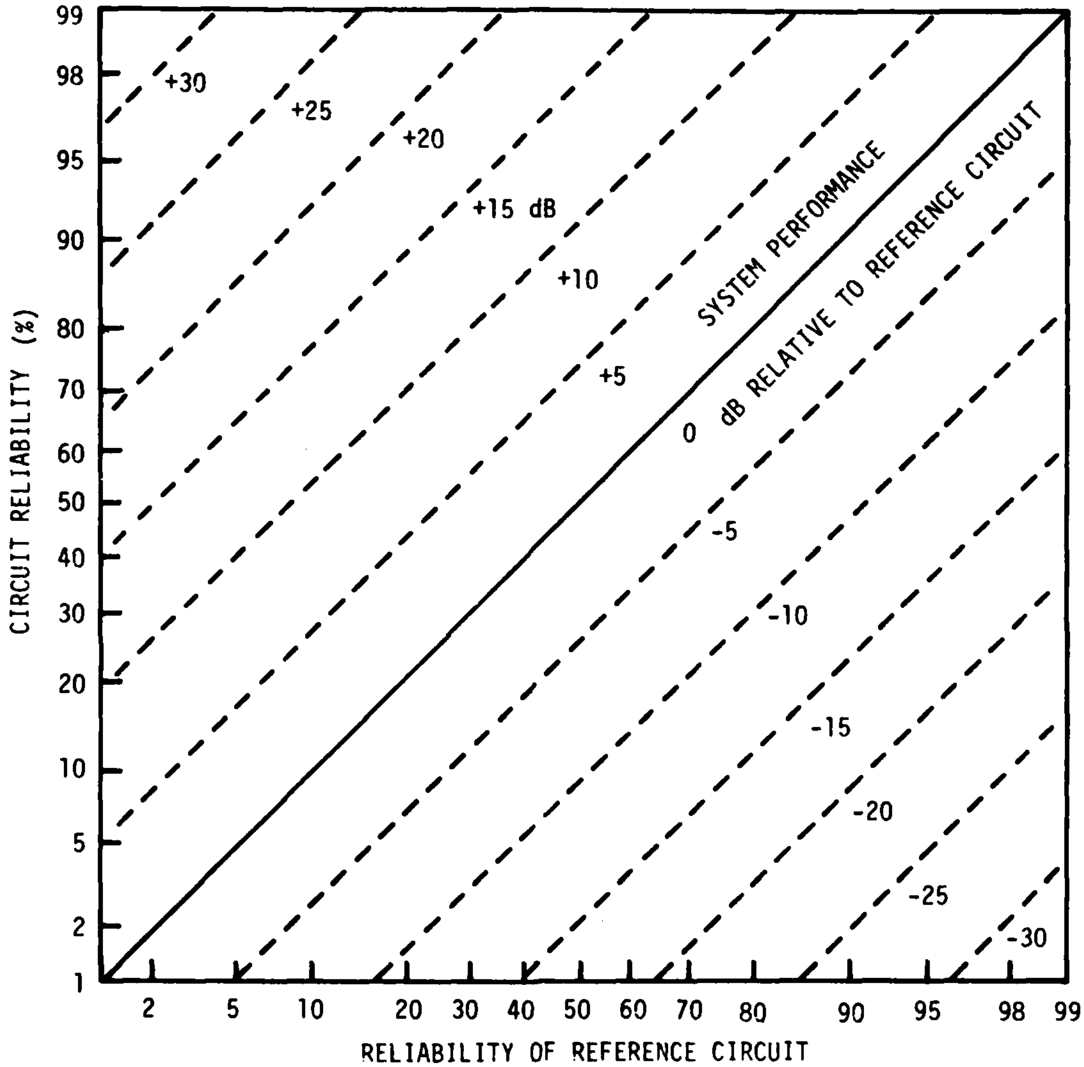


FIGURE 7. CHART TO ESTIMATE CIRCUIT RELIABILITY WHEN CIRCUIT PERFORMANCE IS KNOWN RELATIVE TO A REFERENCE CIRCUIT (SKYWAVE PROPAGATION)

The conclusion which may be drawn is that, if a system gain of 20 dB relative to the reference system was available (lower transmission speeds, coding, higher tolerable error rates, etc.), the theoretical reliability across the North Atlantic would equal or exceed 99 percent. Remember that the theoretical reliability is based on a short-term Rayleigh signal distribution, and the long-term statistics are normal distributions which may fail to account adequately for ionospheric disturbances which exceed the normal day-to-day variations.

4.3 OVERALL SYSTEM PERFORMANCE OF SKYWAVE SYSTEMS

Figure 8 summarizes the expected system performance by ranking the time and location sample points as shown in Appendix B into distributions as a function of circuit location (North Pacific or North Atlantic) and solar-activity level (SSN 10 or 110). It should be noted there is very little difference between high and low solar activity (low is theoretically slightly better), but there is a noticeable difference between the Atlantic and Pacific areas, the Pacific being the better. Figure 9 combines the data from Figure 8 with the data from Figure 7 to illustrate the expected reliability distribution as a function of required S/N ratio for the North Atlantic Circuit. Figure 10 is s similar presentation for the North Pacific. The tabulation in Table 4 shows the theoretical required S/N ratio for simple data transmission systems as a function of transmission rate and tolerable error rate.

Required S/N ratios from Table 4 may be used with Figures 9 and 10 to estimate the overall expected performance of skywave systems in the North Atlantic and North Pacific except when ionospheric storms or disturbances cause the minute-to-minute signal variations to depart markedly from the typical Rayleigh distribution or when the hourly median signal levels fall outside the typical day-to day variations used in this study.

4.4 RF SOUNDING AS A MEANS OF IMPROVING SPECTRUM UTILIZATION OF SKYWAVE CIRCUITS

There have been many investigations undertaken in order to improve the performance of skywave radio communications circuits by using soundings of the ionosphere. The underlying philosophy behind these studies is that by using sounding techniques the radio propagation conditions at any time and any frequency (subject, of course, to the frequency being within the sounding

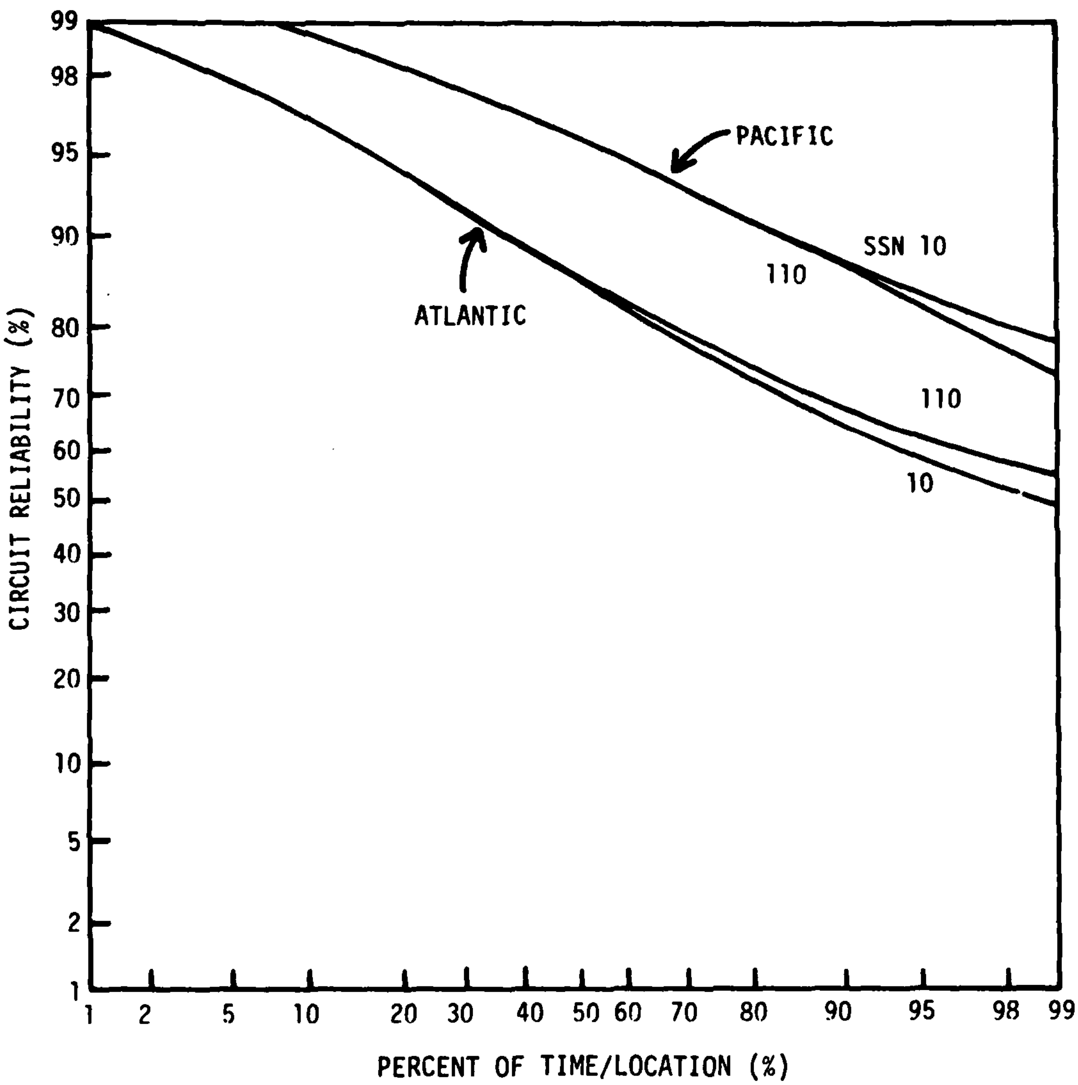


FIGURE 8. SUMMARY GRAPH SHOWING PERCENTAGE OF TIME/LOCATION SAMPLES WHERE REFERENCE CIRCUIT RELIABILITY MAY BE EXPECTED TO EQUAL OR EXCEED THE ORDINATE

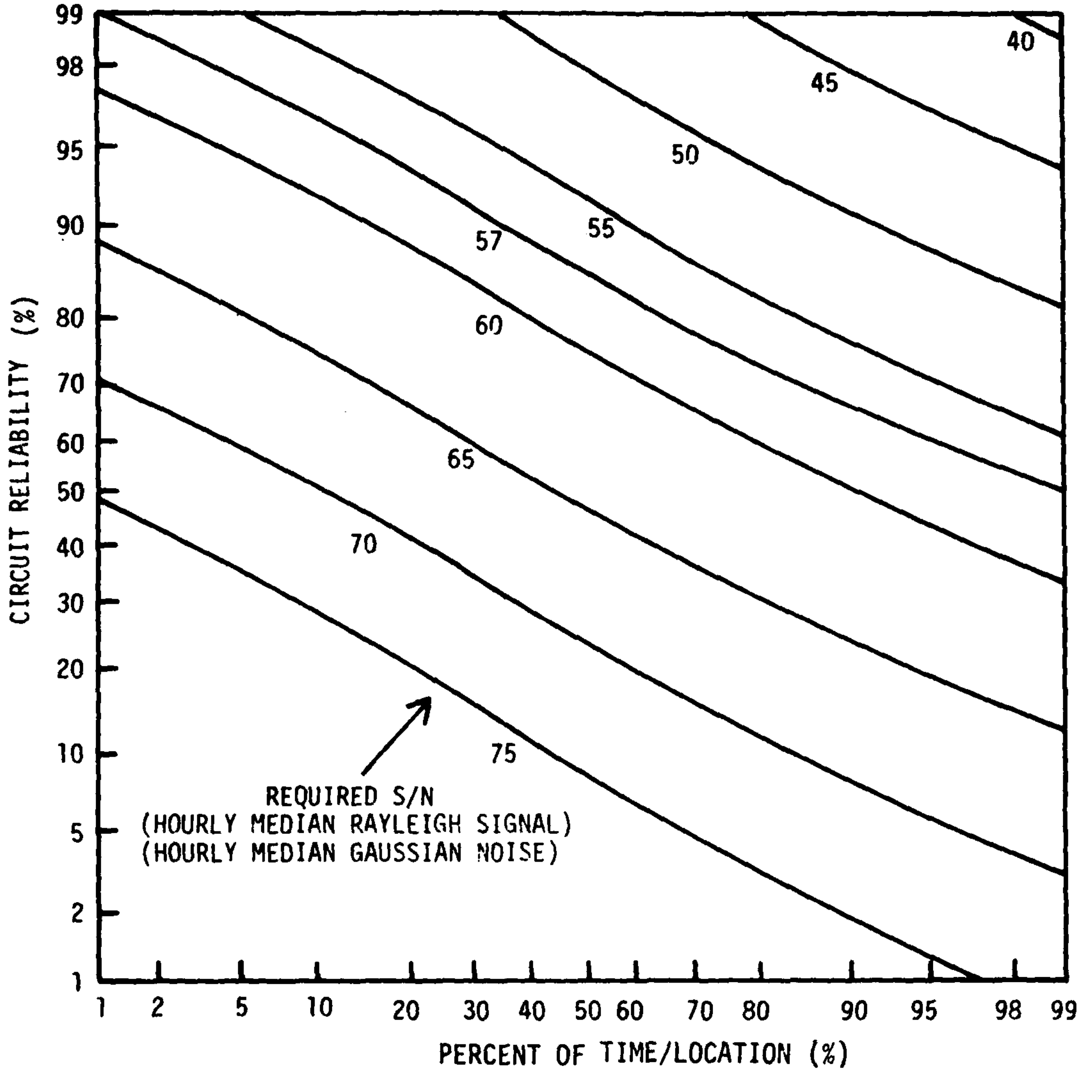


FIGURE 9. CHART SHOWING PERCENTAGE OF TIME/LOCATION SAMPLES VS CIRCUIT RELIABILITY AS A FUNCTION OF REQUIRED S/N RATIO - NEW YORK TO SHANNON - ENTIRE SOLAR CYCLE

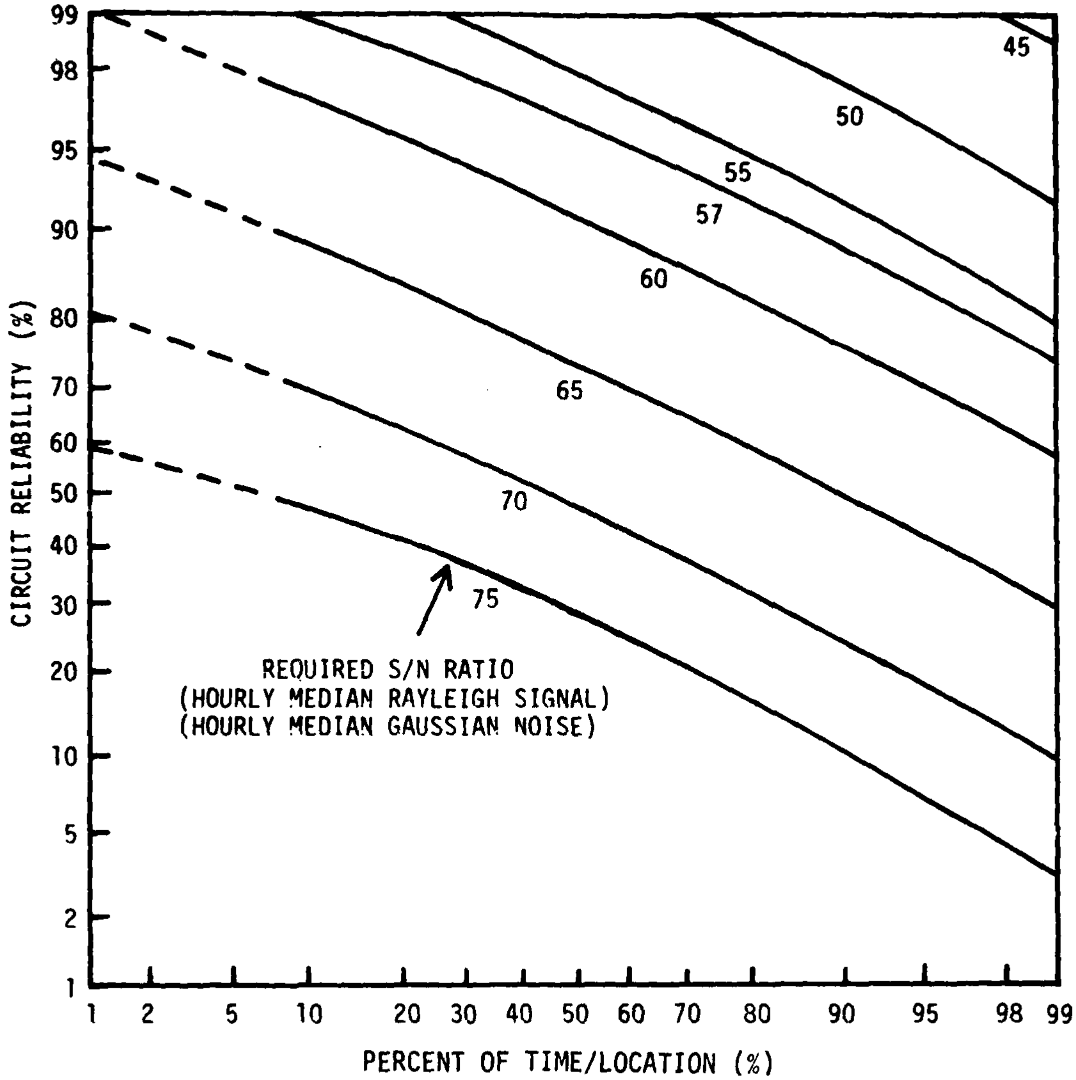


FIGURE 10. CHART SHOWING PERCENTAGE OF TIME/LOCATION SAMPLES VS CIRCUIT RELIABILITY AS A FUNCTION OF REQUIRED S/N RATIO - SAN FRANCISCO TO HONOLULU - ENTIRE SOLAR CYCLE

TABLE 4. THEORETICAL REQUIRED SIGNAL-TO-NOISE DENSITY RATIO (dB) FOR RADIO SIGNALS IN THE PRESENCE OF GAUSSIAN NOISE FOR SELECTED DATA TRANSMISSION SYSTEM (NO SIGNAL PROCESSING OR ERROR CORRECTING CODES)

SYSTEM	BITS PER SECOND	SIGNAL			
		STEADY		RAYLEIGH	
		Binary Error Rate		Binary Error Rate	
		10^{-2}	10^{-3}	10^{-2}	10^{-3}
ON-OFF	1200	44	47	57	69
	600	41	43	54	66
	300	38	40	51	63
	30	28	30	41	53
LIMITER DISCRIMINATOR FREQUENCY SHIFT KEYING	1200	41	43	51	61
	600	38	40	48	58
	300	35	37	45	55
	30	25	27	35	45
DUAL FILTER FREQUENCY SHIFT KEYING	1200	42	44	53	63
	600	39	41	50	60
	300	36	38	47	57
	30	26	28	37	47
DIFFERENTIALLY COHERENT PHASE SHIFT KEYING	1200	37	39*	46	57*
	600	34	36	43	54
	300	31	33	40	51
	30	21	23	30	41

* Reference required S/N used in the analysis

interval) can be readily determined from the sounding observations. Having this information, a radio or communications engineer could then choose to operate his radio equipment at a frequency that is optimally based on sounding data.

There are, however, certain factors that must be taken into consideration when applying sounding to HF frequency management and frequency selection operational scenarios. In order for the sounding data to be directly useful, it is necessary that the radio paths over which communications are to be effected are the same paths for which sounding data are available. There is a dearth of information concerning just how applicable propagation parameters are for paths that differ from paths that were used in deriving the parameters. The degree to which data from one path could be used to infer propagation conditions on another path is dependent upon the mode of propagation. Because the E-region tends to be more stable than the F-region, one would anticipate that E modes could be used to infer propagation conditions on more widely separated paths than F modes. This is borne out somewhat by the work of Rush and Gibbs (1973), for example, in which it is shown that changes in the E-region critical frequency are correlated over larger distances than changes in the F-region.

Another factor that must be considered in using sounding is the problem of transmitting the information obtained from the soundings to both ends of a communication circuit. It matters little that the transmitter end of a circuit is optimized for communication performance if the receiver end does not have knowledge of the frequencies being used. Obviously, there are systematic approaches that could be adopted in order to assure that both ends of the circuit are aware of the frequency used for transmission. (The receiver could cycle through the available frequency allocations in a pre-arranged manner). However, such approaches may be costly and cumbersome, particularly in an experimental program.

Because the ionosphere varies on temporal as well as spatial scales, it is necessary that any information derived from sounding be forwarded to the appropriate control centers with enough time to permit the results to be usefully employed. In the late 1960's, the Institute for Telecommunication Sciences (Slutz et al., 1969) conducted a program to assess how much improvement results when near real-time vertical incidence sounding data were used

to modify HF predictions for circuits operating in the tropics. This study showed that vertical incidence data lead to better or improved predictions only when it was used to predict ionospheric-dependent circuit performance for circuits within one hour of the sounding observations.

Another factor to consider in the employment of soundings for frequency management purposes is the potential interference to selected classes of radio service that could result from the sounding. In recent years, studies have been conducted, primarily by the U. S. Air Force and the Barry Research Corporation, that demonstrate the improvement in communication circuit performance using FM-CW (Chirp) oblique incidence soundings. In some instances, these studies were motivated more from a point of view of assessing the interference environment rather than the application of sounding to improve communication circuit performance.

Data have been collected during a test in the southeastern United States in which a large portion of the HF spectrum was temporarily made available for non-interference sharing among test participants and assigned users. Three radio paths (ranges 1760, 540, and 330 km) were operated 24 hours per day for a five-day period. A double sideband, suppressed-carrier modulation format was used with a 16-tone radio teletype on one sideband and an order-wire voice channel on the other. The sidebands used were reversed each 15 minutes to allow identification of test interference by other spectrum users. During the five-day period, 1049 frequency changes were made using 745 different center frequencies. Although several spectrum users with potentially impacted frequency assignments were notified of test operations before test commencement, only two interference reports were logged, and these were on idle channels which were being monitored but were not transmitting. The key to operating so successfully on a non-interference basis was to automatically scan the entire HF spectrum each ten seconds with a specially configured, microprocessor-controlled receiver (a spectrum monitor). This unit sampled and stored received signal power levels, integrating these values over 5-minute and 30-minute periods.

Figures 11, 12, and 13 display channel occupancy and availability on each of three paths over a 24-hour test period. The shaded region represents the number of available channels out of the 56 frequencies specifically assigned for test use. An available channel is defined to be within the band of

propagating frequencies (determined by an oblique ionospheric sounder) and also clear of interference. It is readily apparent that sounding does not adversely impact on the performance of communication circuits through received interference.

The concept of sounding in an aircraft was used for frequency selection in another test involving a demonstration of an automatic adaptive frequency management system, which was performed from July to September of 1977. Signal-to-noise data were collected automatically using a modified oblique ionospheric sounder which made scans of "candidate" operating frequencies, especially searching for high noise or interference level. After processing the propagation and noise data, the system provided a choice of ten best frequencies from an assigned frequency complement of 133 assignments. These frequencies were printed on a teletype at the sounder receiver's location and automatically transmitted via radio teletype to the sounder transmitter's location. The recommended frequencies were used and evaluated manually to check the reliability of the automatic frequency selection procedure.

The data shown in Figures 14 and 15 were taken during tests in Europe demonstrating real-time spectrum management concepts on a smaller scale than the preceding U. S. tests. This exercise used only a given block of specifically assigned frequencies, but shared these among several test members. The nighttime spectrum covers only 2.25 to 4.35 MHz since these were the only frequencies capable of supporting propagation over the paths used. Notice the display of power thresholds in the figures; the nighttime measurements used a considerably less sensitive threshold which was still surpassed over 90 percent of the time at most frequencies. This congestion of the spectrum at nighttime is typical in most parts of the world.

The above data taken from Air Force-sponsored tests provide some indication that sounding can be employed to improve HF communication circuit performance. However, in order to test this hypothesis, a study with dedicated aircraft and specialized equipment must be employed. Also, specific message codes would have to be used. There is no technical reason why the above-mentioned experiments could not be undertaken by trans-oceanic aircraft operating under FAA scenarios. In fact, a simpler experiment in which aircraft with receivers tuned to only the frequencies available for communication could be

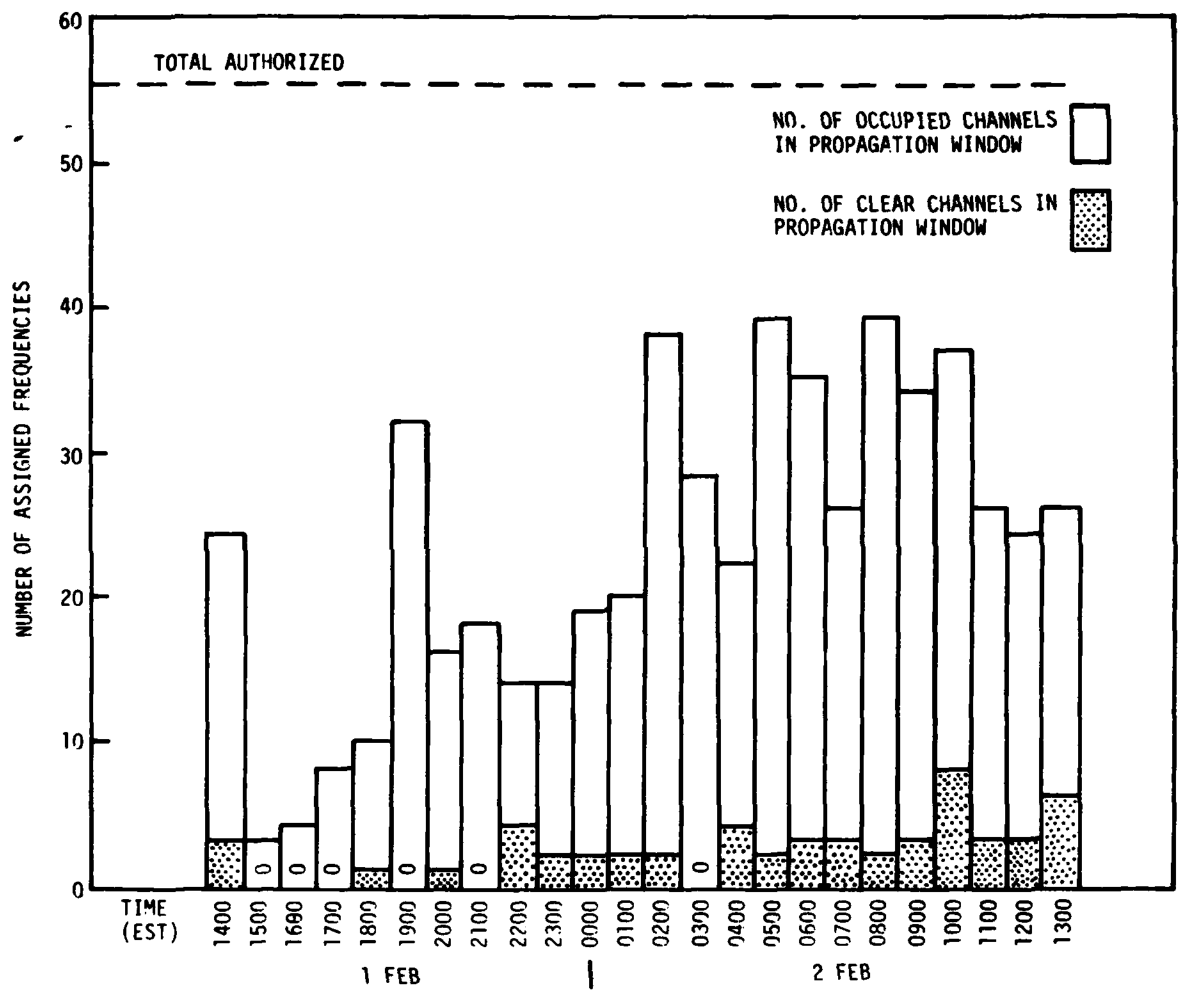


FIGURE 11. ANALYSIS OF UTILITY OF FREQUENCY ASSIGNMENTS IN 24-HR PERIOD, 1960 km PATH

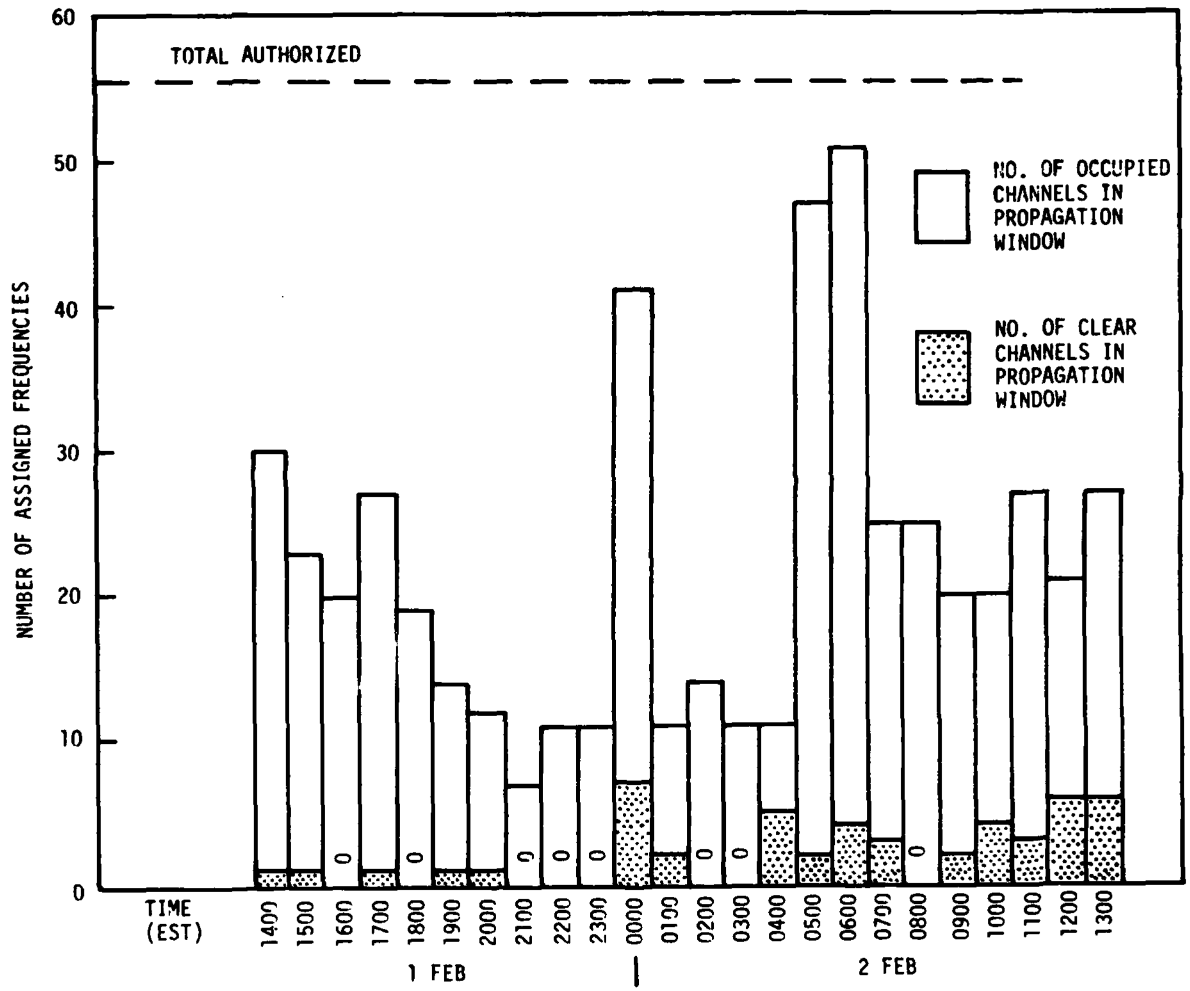


FIGURE 12. ANALYSIS OF UTILITY OF FREQUENCY ASSIGNMENTS IN 24-HR PERIOD, 540 km PATH

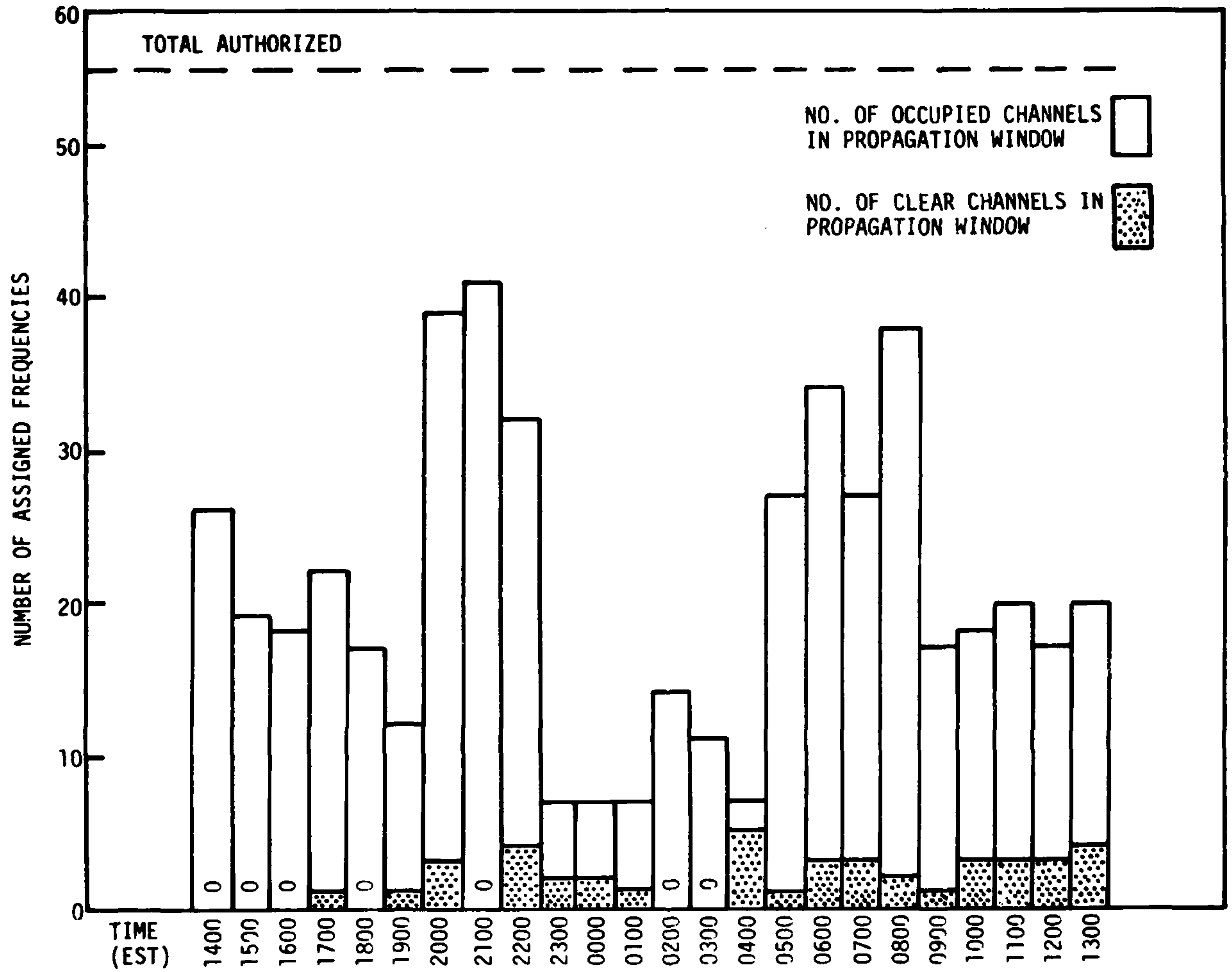


FIGURE 13. ANALYSIS OF UTILITY OF FREQUENCY ASSIGNMENTS IN 24-HR PERIOD, 330 km PATH

DAYTIME HF ENVIRONMENT - DENMARK

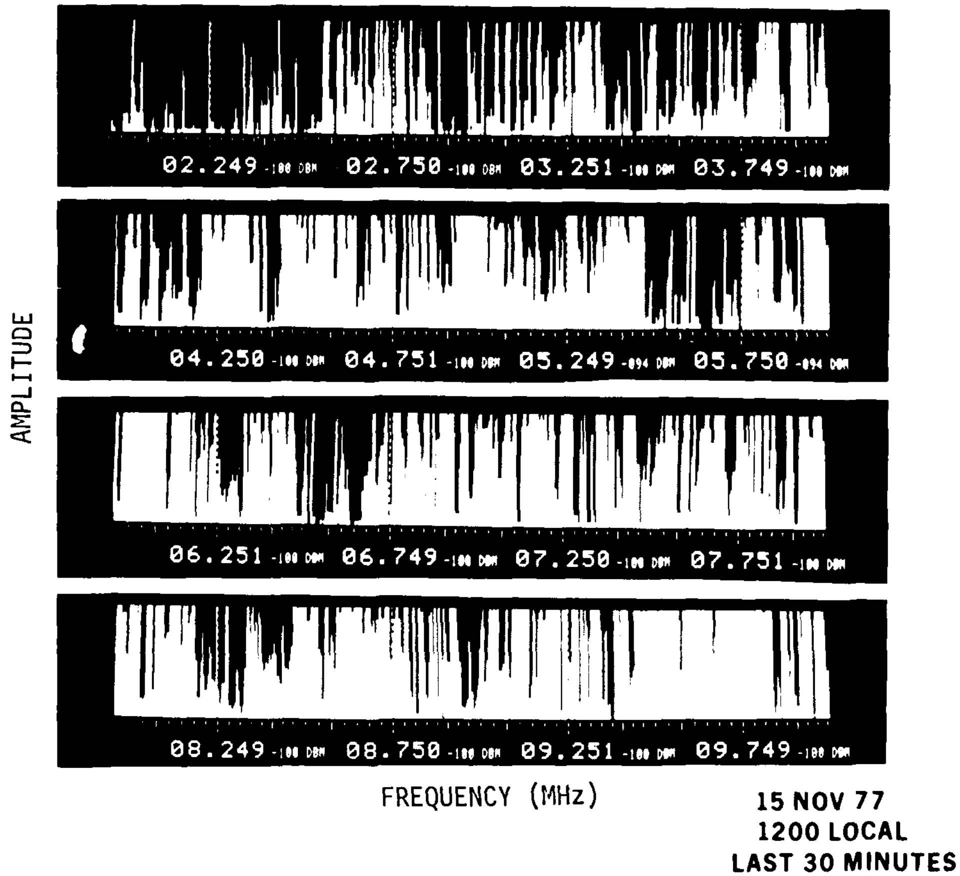
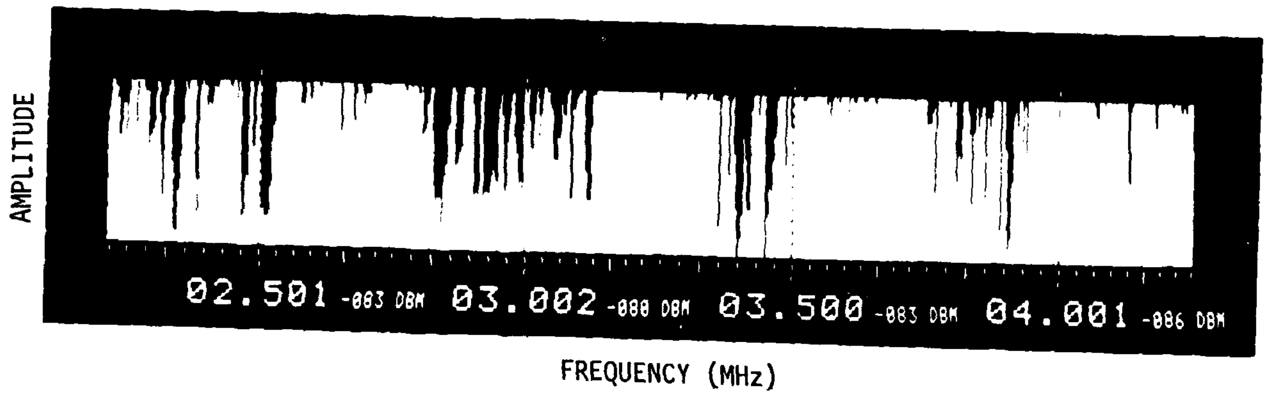


FIGURE 14. DAYTIME HF ENVIRONMENT

NIGHTTIME HF ENVIRONMENT - BELGIUM



25 OCT 77
2030 GMT
LAST 5 MINUTES

FIGURE 15. NIGHTTIME HF ENVIRONMENT

devised. By continuously monitoring the signal quality from a transmitter at a specific location, the aircraft could see the changes in propagation conditions as applied to the available frequencies. Again, this would require dedicated aircraft. It appears at this time, however, that such aircraft would not be available for the experiments, and from a practical viewpoint, the demonstration of sounding to improve HF channel selection does not appear feasible in the near future for FAA applications.

4.5 IONOSPHERIC DISTURBANCES

The ionosphere exhibits considerable systematic variability. If minute-to-minute variations within the hour and the day-to-day variations within the month are averaged, the remaining temporal variations (i.e., diurnal, seasonal, and solar cycles) become well behaved. When the minute-to-minute and day-to-day variations are averaged, the remaining variations characterize what is normally referred to as the quiet ionosphere because the percentage of disturbed days in the month is usually relatively small. Although relatively rare, these disturbances, however, can be quite severe with the severity dependent primarily upon the excess of the available signal-to-noise ratio relative to the required signal-to-noise ratio at the onset of the disturbance.

An indication of the distribution of ionospheric disturbances is shown in Figure 16 with a corresponding representation of their duration shown in Figure 17. Table 5 is a tabulation showing the correlation between intensity of disturbance and disturbance duration. Unfortunately statistics do not appear to be available as to the percentage of time fading was below a specified depth. Table 6, based upon an evaluation of the shortwave broadcast operations of the British Broadcasting Corporation, shows a qualitative evaluation of those disturbances which were considered "noticeable" relative to those considered to be severe. It should be noted that during some periods, apparently during periods of low solar activity, the disturbances were considered negligible to these broadcast operations. It is of interest and of practical importance that disturbances appear most severe during high solar activity since during periods of high solar activity the useful frequency range is greater. Therefore, point-to-point circuits which have an ability to choose between frequencies or use more than one

frequency should be subject to less difficulty than those with a more limited frequency range. In summary, we can conclude that the chances of moving in frequency to minimize the effects of a disturbance are best during the periods that the likelihood of a disturbance is the highest.

It must be emphasized that the severity of ionospheric disturbances depends upon the circuit parameters. Table 7 is an example of comments of radio operators on air-ground circuits as received at Miami, Florida. In Table 7, the circuit evaluation is qualitative and no direct comparison between air-ground operations and broadcast operations is possible. Normally disturbances tend to be most noticeable on those circuits having the lower available signal margins. It should also be noted that frequency changes during disturbances often offer some advantage and, when used, should minimize the fade duration and depth occurrences such as are shown in Figures 16, and 21, and Table 5, or the qualitative signal evaluations of Tables 6 and 7.

In order to combat disturbances, it is desirable that circuits be operating on the theoretically most desirable signal at the onset of the disturbance. Figure 18 shows a sample graph which can be used to develop an operational schedule. To find the optimum frequency (and terminal with which successful communication is most probable), it is necessary only to enter a chart of this type for the proper month and solar-activity level with the GMT and distance from the terminal and to note the theoretically best aeronautical high frequency band. Schedules may be prepared when the flight time is known by drawing a time distance line on the chart (i.e., distance from San Francisco as a function of GMT). This line will yield an operational schedule. If communication fails due to a disturbance, it is useful to have planned frequency changes. Normally, these planned changes would involve trying the next lower aeronautical frequency band first followed by trying the next higher aeronautical frequency band.

Many disturbances are predictable, and a warning service used to be operated by the U. S. Department of Commerce. With the acquisition of better geophysical data (e.g., by the use of satellites), there appears to be a good opportunity to develop a warning system based on these data which would be much better than before. The geophysical data are here (solar-X ray emission, other solar emission, magnetic field disturbances, etc.); the need is to translate these phenomena into their effects within an appropriate time frame.

4.6 AIR-TO-AIR RANGE

To complement or as a back-up to skywave communication between aircraft and ground terminals, it appears desirable to establish the theoretical feasibility of message relay between aircraft. For aircraft flying at 30,000 feet (10 km), it appears reasonable to expect that propagation will essentially free space out to about 800 kilometers. Beyond the free space range, the signal levels will decrease rapidly depending somewhat upon atmospheric conditions. Figures 19, 20, and 21 illustrate the expected distance variation of available signal level and the range of required signal levels to bracket the normal seasonal and diurnal variations of expected noise levels. The required signal-to-noise density ratio of 39 dB corresponds to a 10^{-3} binary error rate at a 1200 bits-per-second transmission rate in a differentially coherent phase shift keying system without diversity reception. The atmospheric noise level is derived from CCIR Report 322 and is based on hourly median noise not exceeded more than 10 percent of the days. A 400-watt transmitter power and antennas equivalent to an isotropic antenna on the aircraft are assumed. Figure 19, 20, and 21 suggest that the theoretical range extends to the limit of free space propagation with a better than 20 dB margin of error at 3 and 6 MHz and with a better than 30 dB margin of error at 18 MHz.

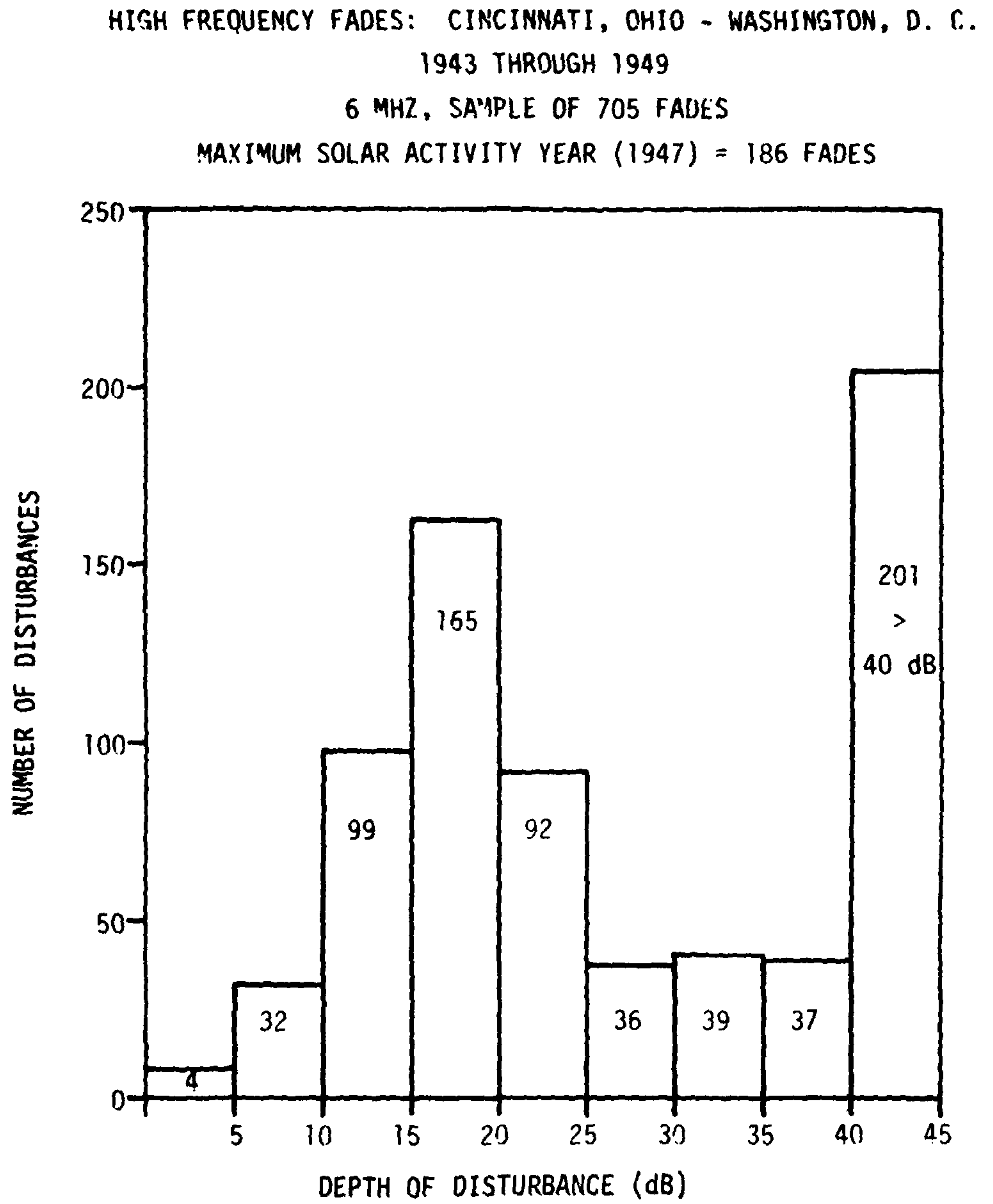


FIGURE 16. SAMPLE CHART SHOWING A SAMPLE FREQUENCY DISTRIBUTION OF HIGH-FREQUENCY SKYWAVE DISTURBANCES

HIGH FREQUENCY FADES
CINCINNATI, OHIO - WASHINGTON, D. C.
1943 THROUGH 1949
6 MHZ

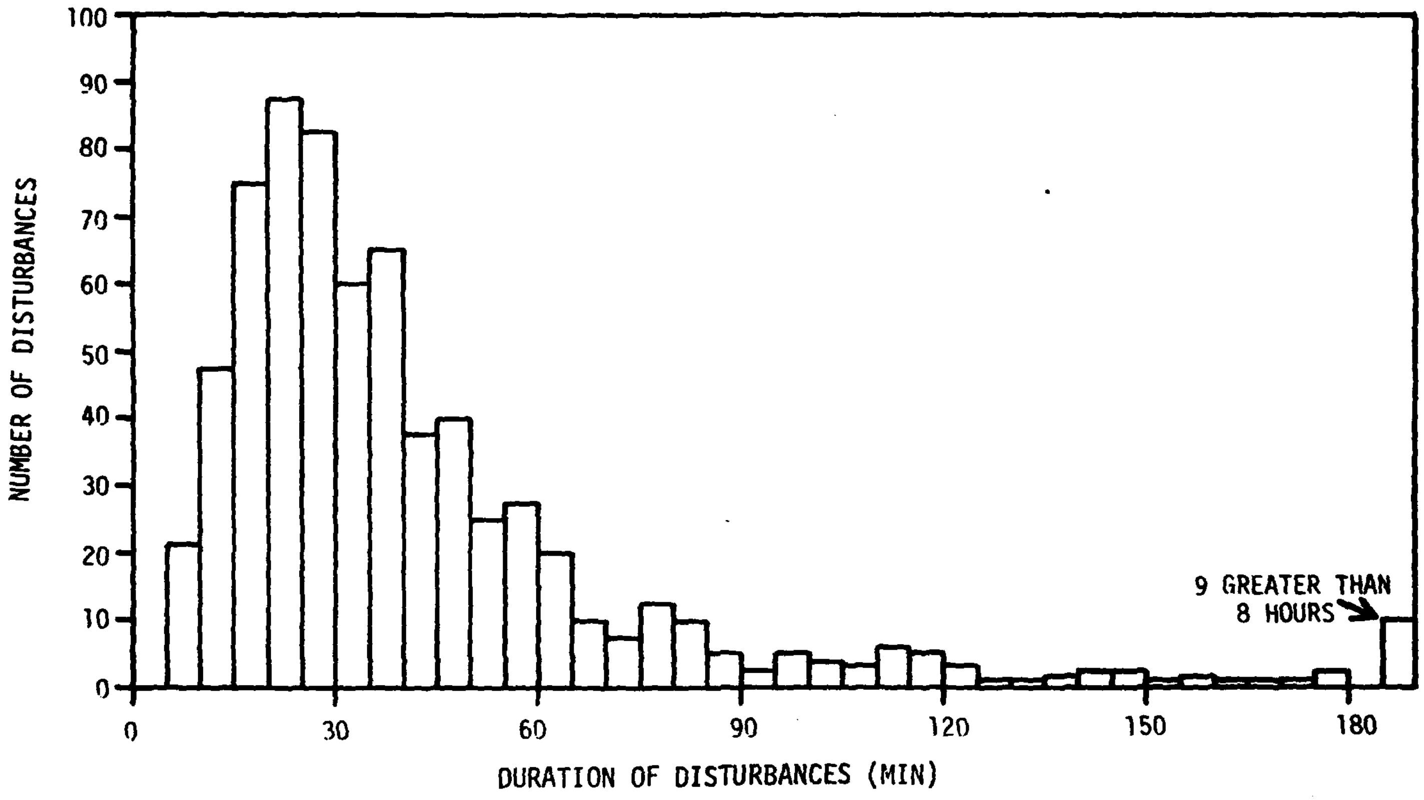


FIGURE 17. SAMPLE CHART SHOWING A SAMPLE FREQUENCY DISTRIBUTION OF HIGH-FREQUENCY SKYWAVE DISTURBANCES

TABLE 5. SAMPLE CHART SHOWING THE INTER-RELATIONSHIP BETWEEN DISTURBANCE DEPTH AND DISTURBANCE DURATION OF HIGH-FREQUENCY SKYWAVE SIGNALS

HIGH FREQUENCY FADES
CINCINNATI, OHIO - WASHINGTON, D. C.
1943 THROUGH 1949
6 MHz
SAMPLE OF 705 FADES
MAX SOLAR ACTIVITY YEAR (1947) = 186 FADES

>180	0	0	0	0	0	0	0	1	9
180									
	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	1	0	0	0
	0	0	0	0	0	0	1	0	0
	0	0	0	0	0	0	0	0	2
	0	0	0	0	0	0	0	0	1
	0	0	0	0	0	0	0	0	1
	0	0	0	0	0	0	0	1	0
	0	0	0	1	0	0	0	0	2
	0	0	0	0	1	0	0	1	1
	0	0	0	0	0	0	0	0	1
	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	3
120									
	0	0	0	0	1	0	1	1	3
	0	0	0	0	0	0	0	0	7
	0	0	0	0	0	1	0	0	1
	0	0	0	1	0	0	1	0	2
	0	0	0	1	0	0	0	1	3
	0	0	0	0	0	0	0	0	3
	0	0	0	0	0	0	1	2	3
	0	0	0	1	2	0	0	0	9
	0	0	0	2	1	1	1	2	6
	0	0	0	1	0	0	3	0	4
	0	0	1	1	1	0	1	1	6
	0	1	2	2	1	1	0	0	11
60									
	0	0	2	2	5	0	3	3	13
	0	1	1	4	1	1	3	2	12
	0	1	5	8	5	2	3	2	13
	0	1	4	5	5	3	4	3	14
	0	1	8	18	9	2	3	7	15
	0	2	7	9	15	5	4	2	15
	1	4	18	26	12	3	1	1	17
	0	11	22	24	11	6	2	1	10
	1	5	12	28	11	6	2	4	8
	1	6	6	17	8	1	2	1	3
	0	0	9	6	2	1	3	1	1
	0	0	0	0	0	0	0	0	0
0									
	5	10	15	20	25	30	35	40	>40

DISTURBANCE DEPTH (dB)

TABLE 6. ASSESSMENT OF BRITISH BROADCASTING CORPORATION† RADIO PROPAGATION DISTURBANCES

Percentage of Days Per Year

Year	Noticeable Disturbance (%)	Severe Disturbance (%)
1944	2.5	n*
1945	2.2	n*
1946	14.3	6.0
1947	25.5	9.3
1948	21.6	6.0
1949	19.2	6.0
1950	8.5	1.6
1951	8.5	4.9
1952	1.6	0.3
1953	0.3	0.3
1954	0	0
1955	1.9	0.5
1956	15.1	7.4
1957	20.8	12.6
1958	14.3	8.2
1959	12.6	7.7
1960	8.2	4.8
1961	2.2	1.6
1962	1.1	0.8
1963	1.9	0.8
1964	0	0
1965	0	0
1966	5.2	2.2
1967	4.7	0.8
1968	4.9	3.6
1969	7.9	3.8
1970	8.2	5.8
1971	2.2	1.1
1972	4.4	3.3
1973	2.7	1.6

*NOT AVAILABLE

†Source: Louis J. Prechner, External Broadcasting Engineering Department, BBC Annual Report 1973: Ionospheric Statistics and So Forth, Feb 1974.

TABLE 7. SAMPLE COMMENTS OF AERONAUTICAL RADIO, INC.* CONCERNING RECENT RECEPTION ON SKYWAVE SIGNALS AT MIAMI

HF PROPAGATION DISTURBANCES - MIAMI

	GMT (HRS)			
1978	TIME START	TIME END	SEVERITY	COMMENTS
MAY				
26	1300	2200	MODERATE	High frequencies best; 8 MHz & lower--poor.
28	1300	1600	MODERATE	Signals vary - generally weak
29-30	2000	0300	MODERATE	11 MHz remained in primary use
JUNE				
01	1300	1900	MODERATE	All frequencies unstable and weak
02	1300	1900	MODERATE	All frequencies unstable and weak
22	1630	1835	MODERATE	Fade and skip all frequencies
22	1700	1800	MODERATE	Unable work any gnd stns--no signals
22	2100	2400	SLIGHT	Signals weak all frequencies
23	2300	0015	SLIGHT	Weak signals
24	1100	1900	SLIGHT	Weak signals, particularly after 1500 Z
25	1800	2300	MODERATE	Unstable all frequencies, in and out
26	1915	2300	MODERATE	Weak signals
27	1430	1630	SLIGHT	Signals weak, fair during remainder of day
30	1500	1745	MODERATE	Signals distorted with fade, ground & air
30	1840	2330	MODERATE	Weak sigs. all freqs.,slight improve.2300/30
JULY				
05	1905	2200	MODERATE	NYC and SJU weak
11	1100	1900		Signals almost normal; Static and rain static
AUGUST				
01	1500	2200	MODERATE	Signals not solid; Has interruptions
02	1500	2200	SEVERE	Signals dropping out sharply
04	1950	2035	MODERATE	All sigs. weak. SJU unhrd. NYC 1 to 2
05	2000	2155	SEVERE	NYC, SJU, and some acft very weak
05	1700	1845	MODERATE	Heavy static makes evaluation impossible.
11	1500	1700	MODERATE	Signals depressed
12	1844	2045	MODERATE	Signals weak with some skip
19	1050	1810	SLIGHT	Signals weak with some skip
22	1100	1900	SLIGHT	Signals weaker than normal

*Source: Memorandum letter from Richard J. Covell, Manager of Air-Ground Projects, 18 August 1978.

OPTIMUM AERONAUTICAL BAND FOR COMMUNICATION ON THE SAN FRANCISCO HONOLULU ROUTE DECEMBER - HIGH SOLAR ACTTVITY

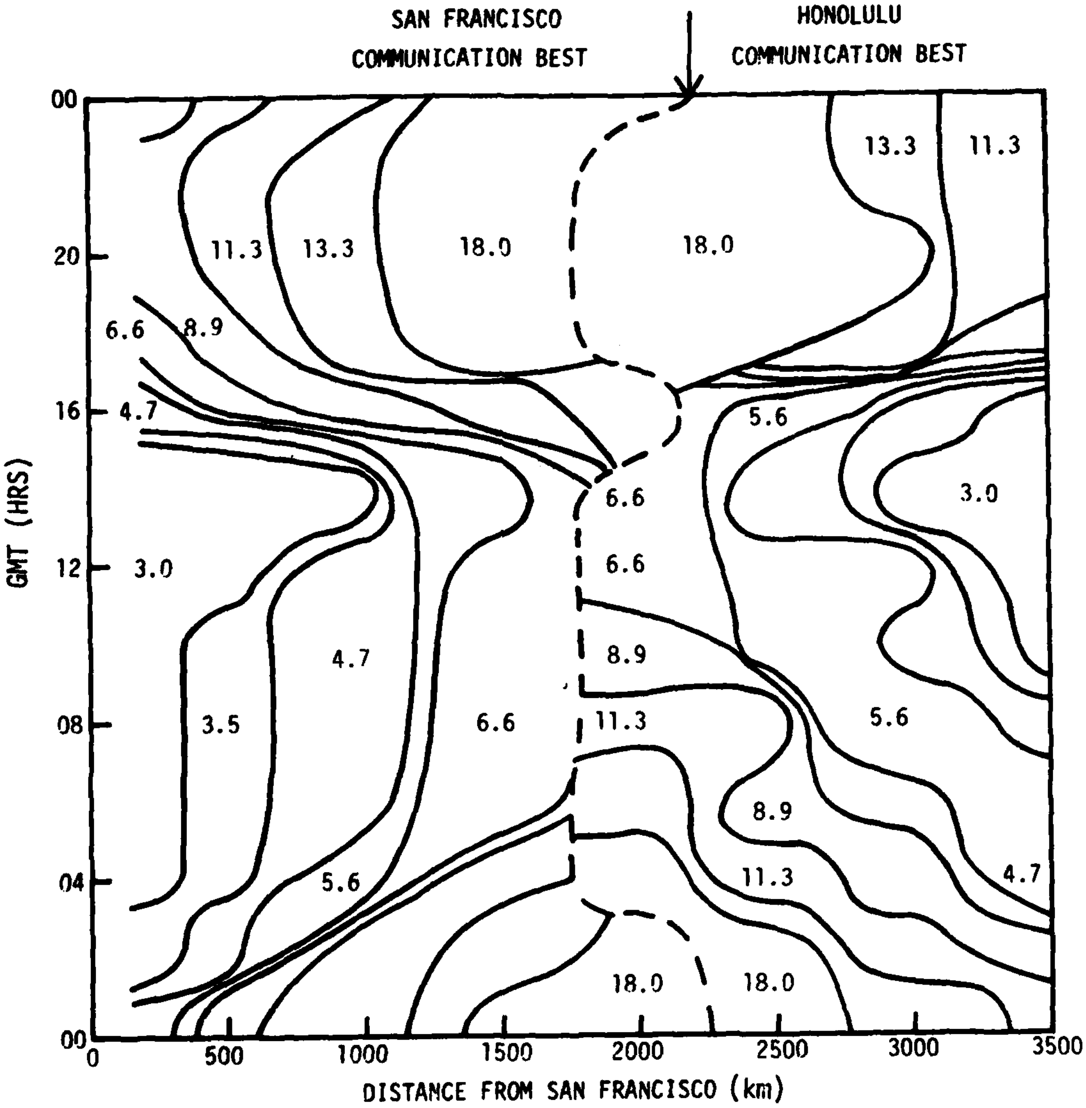
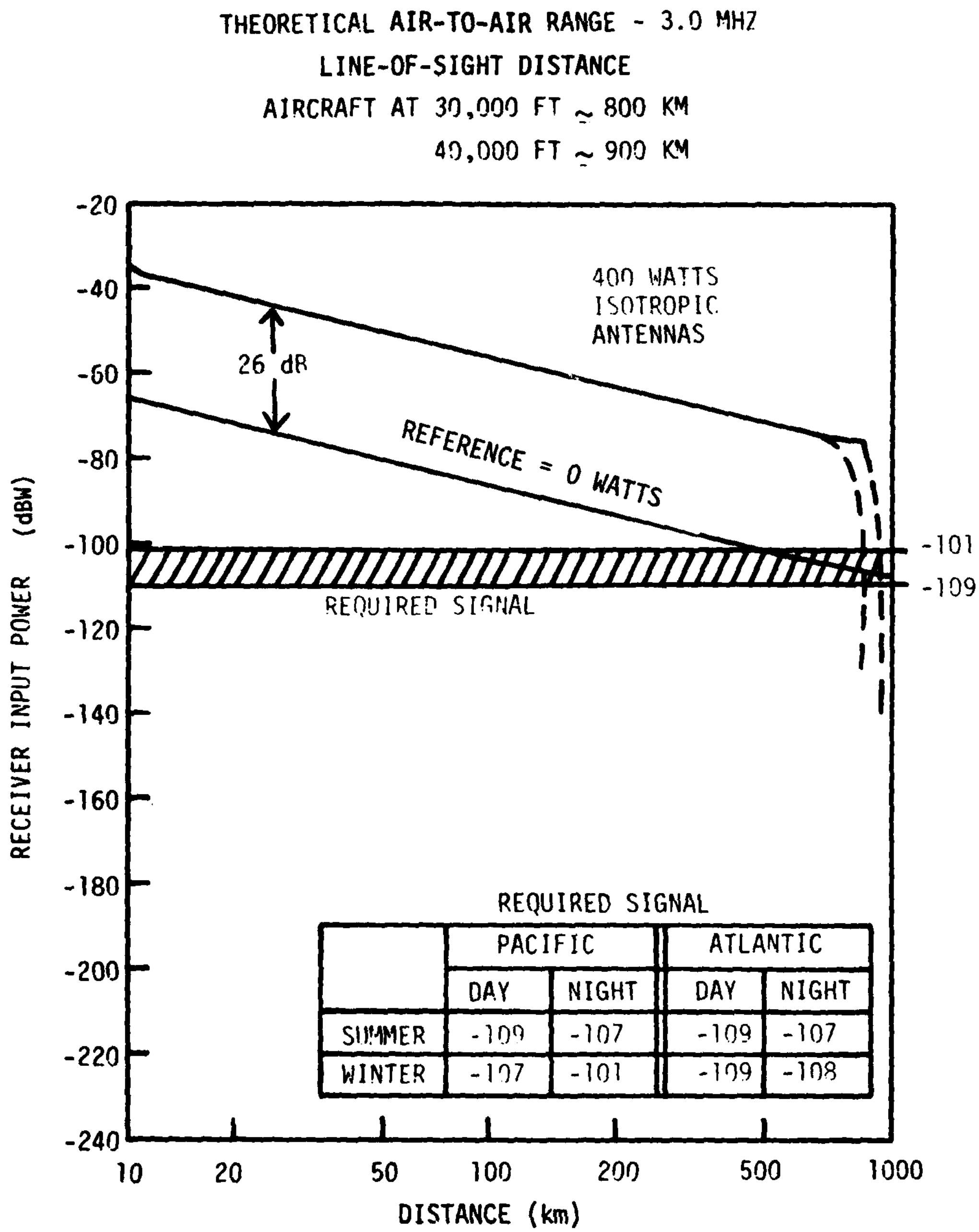


FIGURE 18. SAMPLE GRAPH WHICH COULD BE USED TO ASSIST IN THE SELECTION OF A THEORETICALLY OPTIMUM AERONAUTICAL CHANNEL



	PACIFIC		ATLANTIC	
	DAY	NIGHT	DAY	NIGHT
SUMMER	-109	-107	-109	-107
WINTER	-107	-101	-109	-108

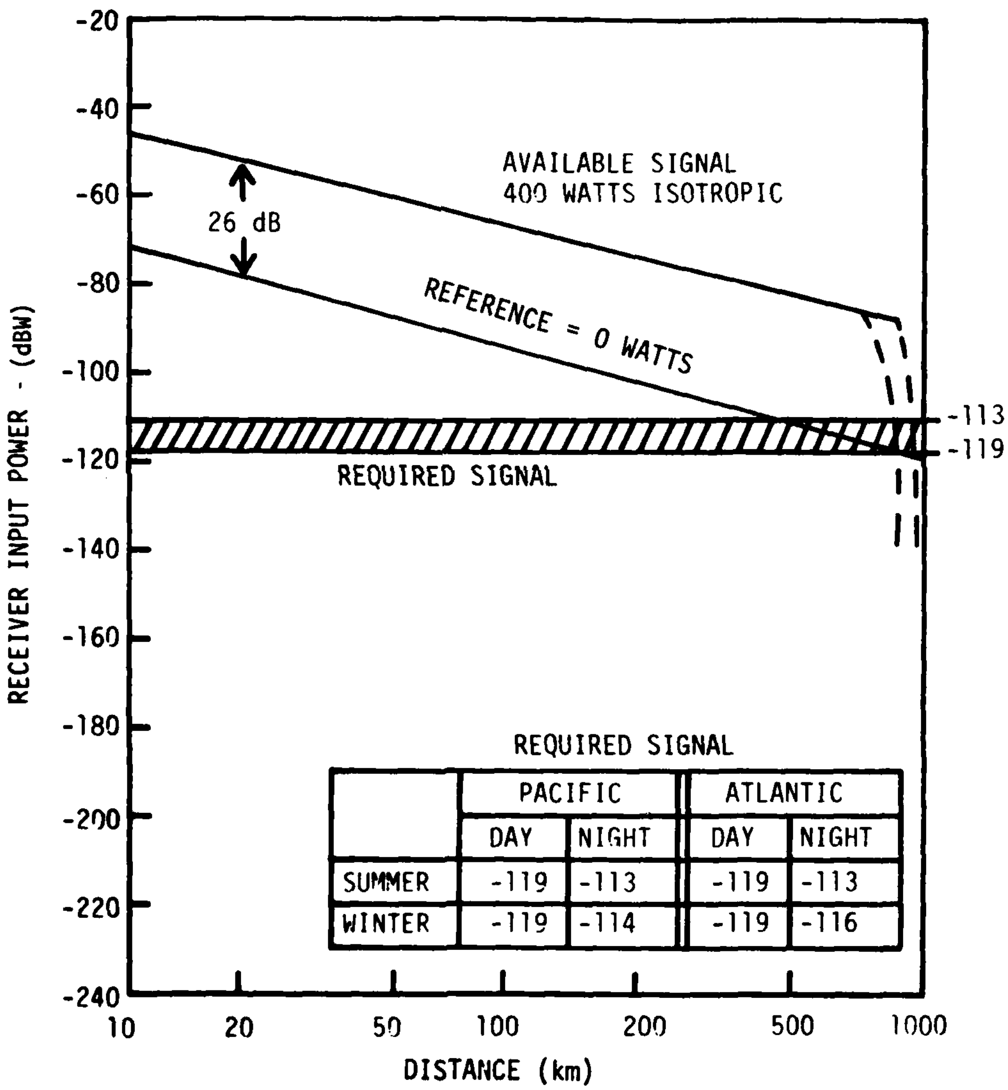
FIGURE 19. CHART SHOWING THEORETICAL AIR-TO-AIR RANGE AT 3 MHz

THEORETICAL AIR-TO-AIR RANGE - 6.0 MHZ

LINE-OF-SIGHT DISTANCE

AIRCRAFT AT 30,000 FT ~ 800 KM

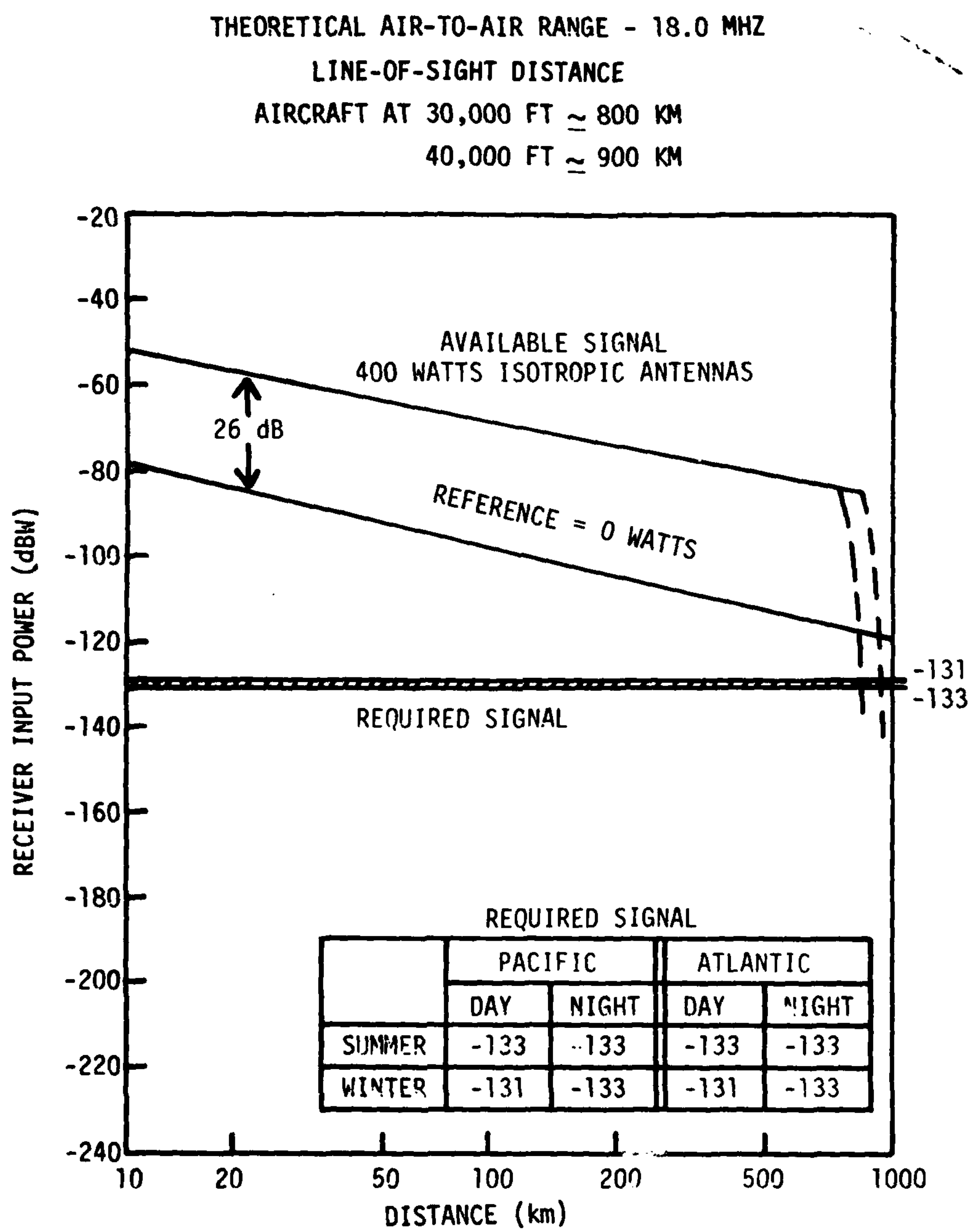
40,000 FT ~ 900 KM



REQUIRED SIGNAL

	PACIFIC		ATLANTIC	
	DAY	NIGHT	DAY	NIGHT
SUMMER	-119	-113	-119	-113
WINTER	-119	-114	-119	-116

FIGURE 20. CHART SHOWING THEORETICAL AIR-TO-AIR RANGE AT 6 MHz



	PACIFIC		ATLANTIC	
	DAY	NIGHT	DAY	NIGHT
SUMMER	-133	-133	-133	-133
WINTER	-131	-133	-131	-133

FIGURE 21. CHART SHOWING THEORETICAL AIR-TO-AIR RANGE AT 18 MHz

5. CONCLUSIONS

Maintaining air-traffic contact via high-frequency skywave digital communication systems appears theoretically attractive and could merit experimental verification.

The likelihood of success appears to be dependent upon:

1) using the best frequencies;
2) communicating between the aircraft and ground terminals at either end of the circuit; and
3) determining by experiment the effects of ionospheric disturbances on air-traffic communications.

6. REFERENCES

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APPENDIX A

BASIC SIGNAL-TO-NOISE RATIO REQUIREMENTS FOR DIGITAL COMMUNICATION SYSTEMS

Required signal-to-noise ratios depend not only upon the characteristics of the signal and of the noise, but also upon the type of modulation and detection used. ("Required Signal-to-Noise Ratios for HF Communication Systems," Hiroshi Akima, Gene G. Ax, Wesley M. Beery, ESSA Technical Report, ERL-131-ITS92, August 1969.) This appendix considers four basic digital systems:

- On-Off Binary Digital System,
- Limiter/Discriminator Frequency Shift Keying,
- Dual Filter Frequency Shift Keying,
- Differentially Coherent Phase Shift Keying.

1. On-Off Binary Digital System

Figure A-1 shows the basic performance of an On-Off Binary Digital System, and Figure A-2 shows the expected degradation of the system in the presence of a Rayleigh fading signal.

2. Limiter/Discriminator FSK Binary Digit System

Figure A-3 shows the basic performance, and Figure A-4 shows the Rayleigh fading degradation.

3. Dual-Filter FSK Binary Digit System

Figure A-5 shows the basic performance, and Figure A-6 the Rayleigh fading degradation.

4. Differentially-Coherent PSK Binary Digit System

Figure A-7 shows the basic performance, and Figure A-8 shows the Rayleigh degradation.

Figures A-1 through A-8 assume a Gaussian noise with no diversity in the reception of the signal. The S/N requirements change somewhat depending upon the type of noise and also change markedly if diversity reception systems are used. Figure A-9 shows the theoretical effect of other noise types (V_d is an index of the impulse nature of the noise) upon a steady state (direct wave) signal, while Figure A-10 shows the theoretical effect of other noise types on the Rayleigh fading (skywave) signal including the interaction with diversity systems. Figures A-9 and A-7, which apply to noncoherent frequency shift keying (NCFSK) systems, illustrate the importance of noise type

and the use of diversity systems at the higher data rates. Similar effects occur for other digital systems.

Table 4 in the body of the report is based on Figures A-1 through A-8, adjusted for various transmission rates.

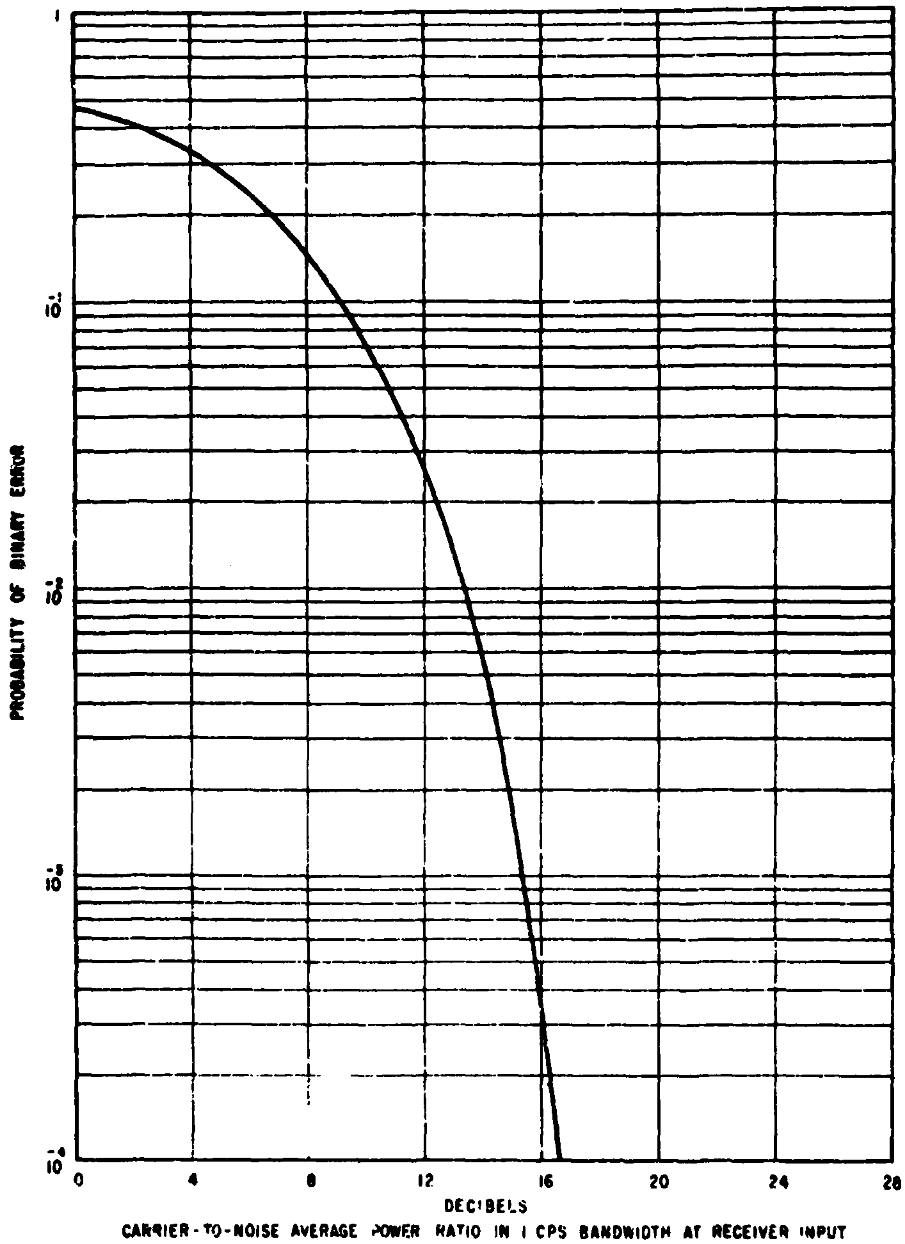

FIGURE A-1. BASIC PERFORMANCE OF "ON-OFF" BINARY DIGIT SYSTEM FOR TRANSMISSION RATE OF ONE BAUD WITH NONFADING CARRIER AND RANDOM NOISE

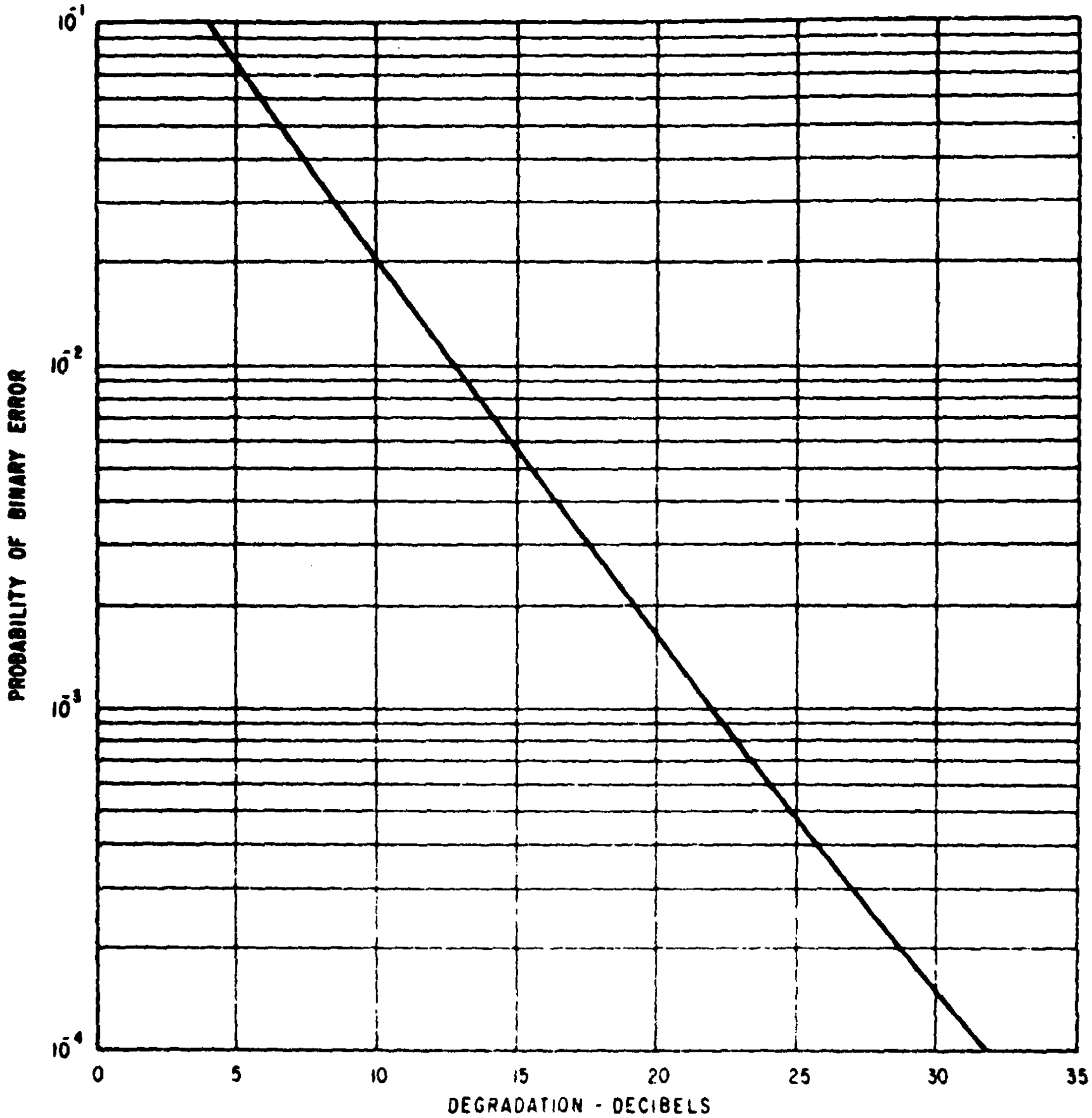

FIGURE A-2. DEGRADATION DUE TO RAYLEIGH-FADING CARRIER: "ON-OFF" SYSTEM

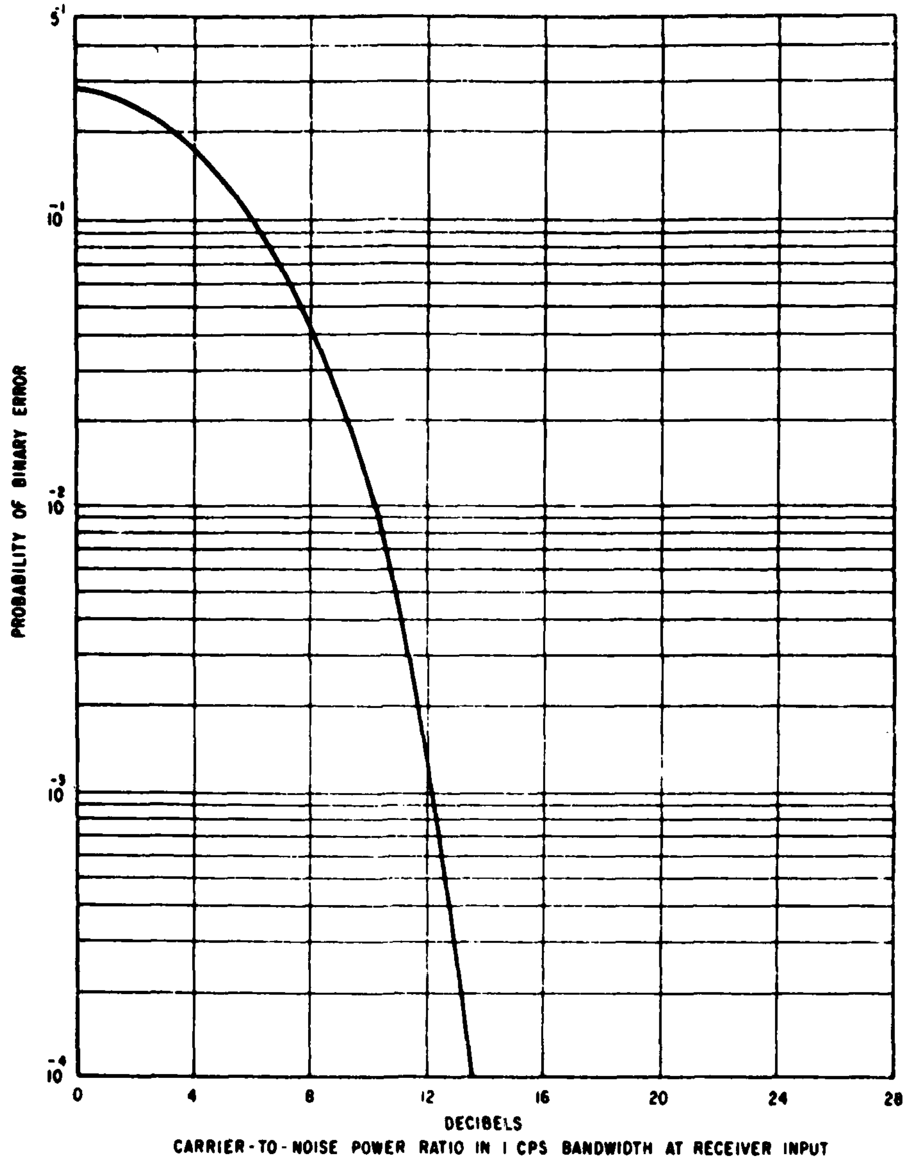

FIGURE A-3. BASIC PERFORMANCE OF LIMITER-DISCRIMINATOR FSK BINARY DIGIT SYSTEM FOR TRANSMISSION RATE OF ONE BAUD WITH NONFADING CARRIER AND RANDOM NOISE

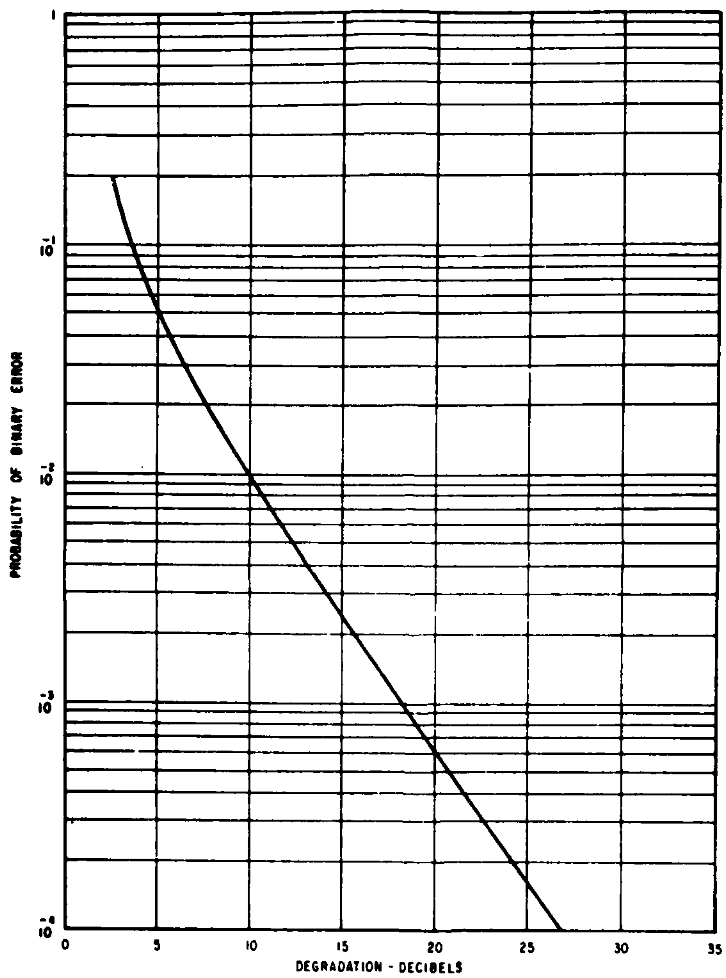

FIGURE A-4. DEGRADATION DUE TO RAYLEIGH-FADING CARRIER: LIMITER-DISCRIMINATOR FSK

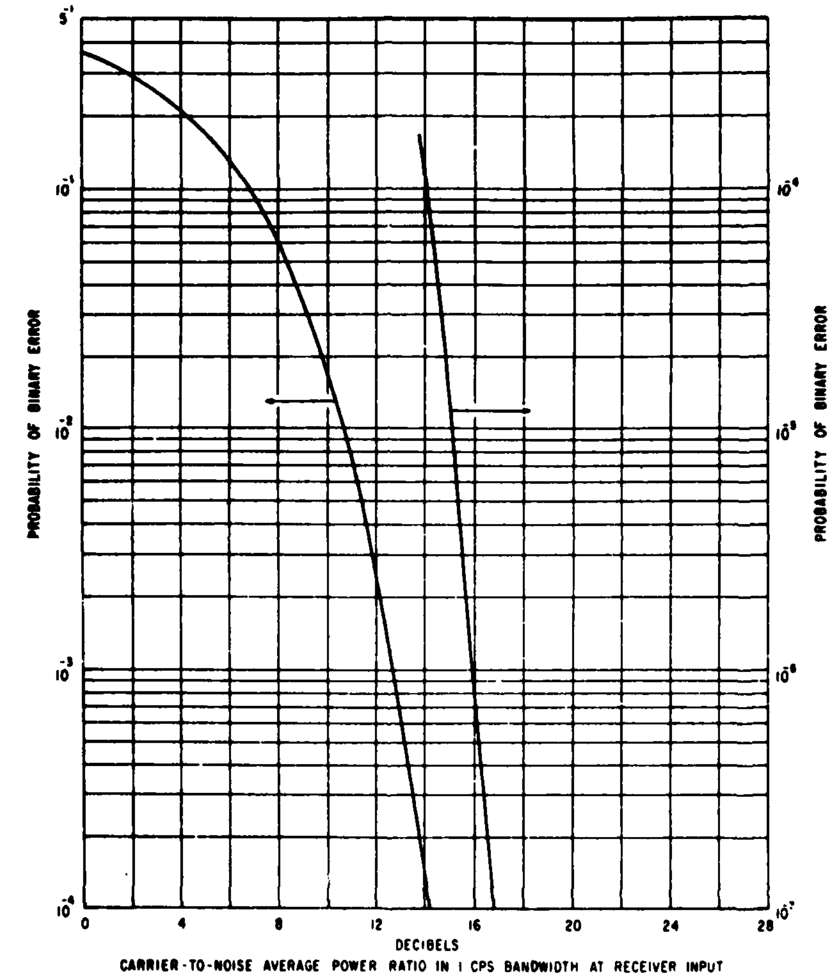

FIGURE A-5. BASIC PERFORMANCE OF DUAL-FILTER FSK BINARY DIGIT SYSTEM FOR TRANSMISSION RATE OF ONE BAUD WITH NONFADING CARRIER AND RANDOM NOISE

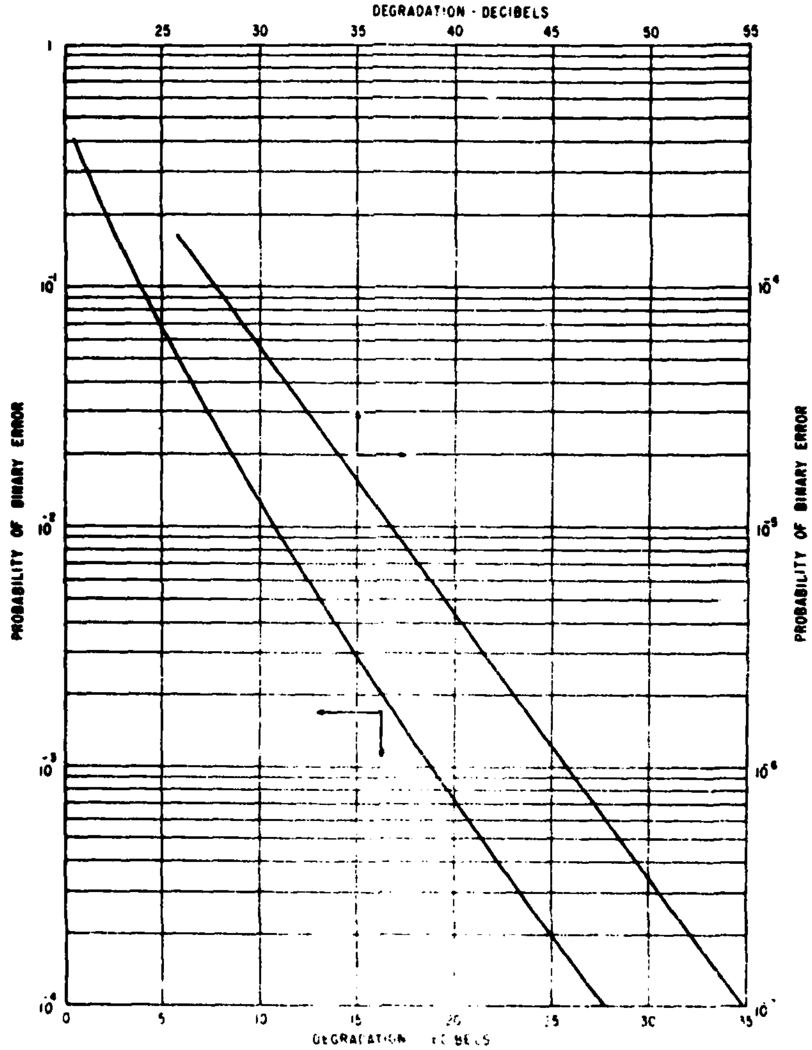

FIGURE A-6. DEGRADATION DUE TO RAYLEIGH-FADING CARRIER: DUAL-FILTER FSK

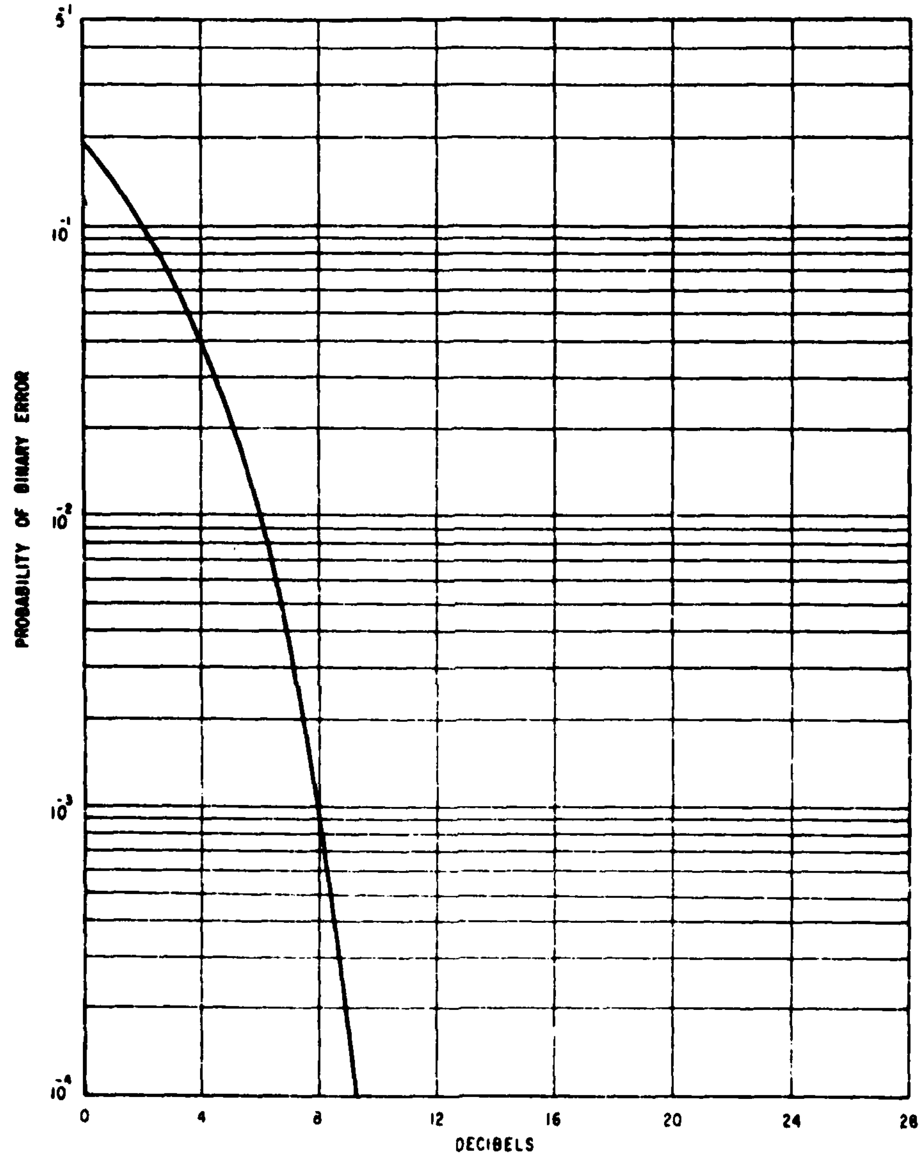

FIGURE A-7. BASIC PERFORMANCE OF DIFFERENTIALLY COHERENT PSK BINARY DIGIT SYSTEM FOR TRANSMISSION RATE OF ONE BAUD WITH NONFADING CARRIER AND RANDOM NOISE

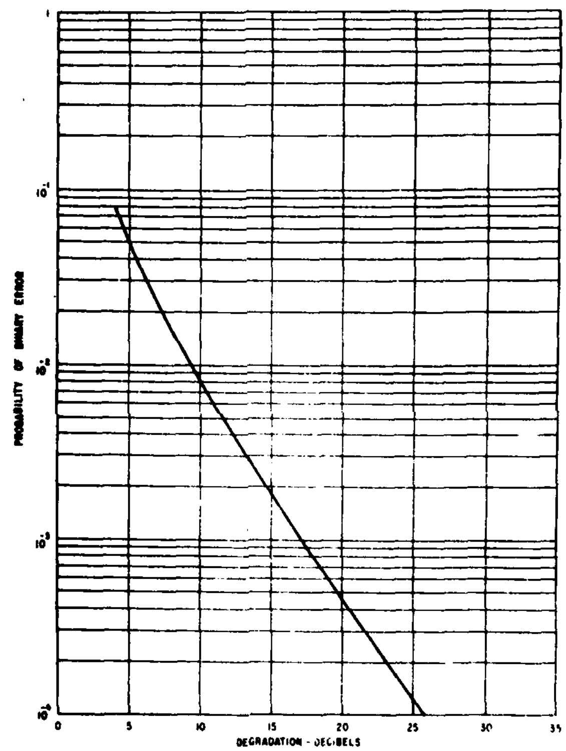

FIGURE A-8. DEGRADATION DUE TO RAYLEIGH-FADING CARRIER: DIFFERENTIALLY COHERENT PSK SYSTEM

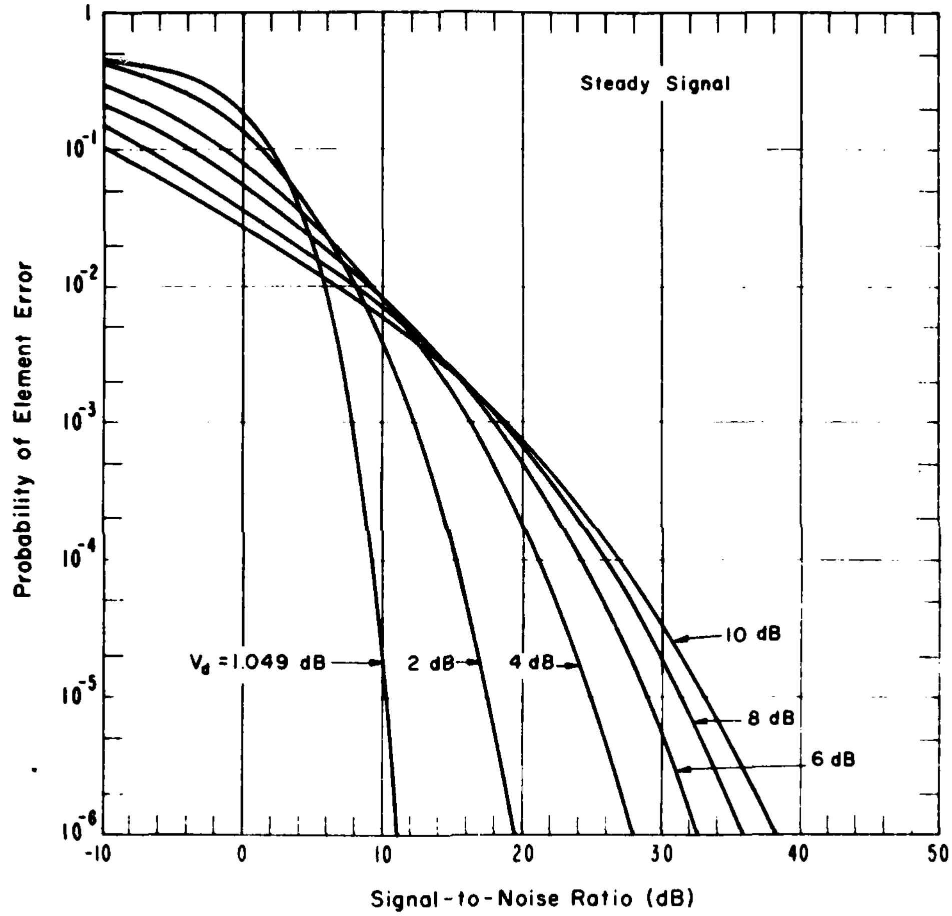

FIGURE A-9. ELEMENT ERROR PROBABILITIES IN A SINGLE-CHANNEL NCFSK SYSTEM UNDER STABLE CONDITIONS. (SIGNAL-TO-NOISE RATIO IS THE RATIO OF SIGNAL POWER TO AVERAGE NOISE POWER, AND V_d IS THE RATIO OR RMS TO AVERAGE OF THE NOISE ENVELOPE VOLTAGE, BOTH MEASURED AT THE INPUT TO THE LIMITER IN A LIMITER-DISCRIMINATOR DEMODULATOR, AND MEASURED IN A BANDWIDTH EQUIVALENT TO THE SUM OF THE BANDWIDTHS OF THE TWO FILTERS IN A DUAL-FILTER DEMODULATOR. MODULATION INDEX IS ASSUMED TO BE NOT LESS THAN UNITY, AND NO LOW-PASS FILTER IS USED BEFORE THE DECISION-MAKING CIRCUIT.)

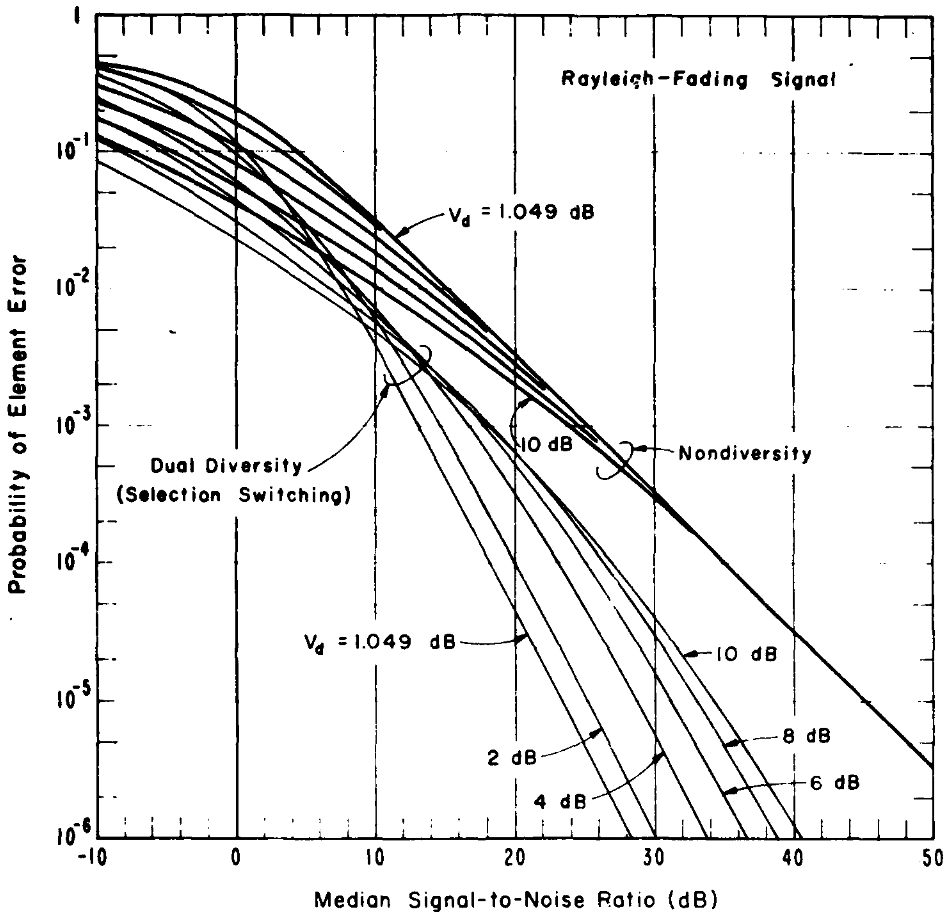

FIGURE A-10. ELEMENT ERROR PROBABILITIES IN AN SINGLE-CHANNEL NCFSK SYSTEM UNDER RAYLEIGH-FADING CONDITIONS WITH NO DIVERSITY AND DUAL SELECTION-SWITCHING DIVERSITY. (MEDIAN SIGNAL-TO-NOISE RATIO IS THE RATIO OF MEDIAN SIGNAL POWER TO AVERAGE NOISE POWER, AND V_d IS THE RATIO OF RMS TO AVERAGE OF THE NOISE ENVELOPE VOLTAGE, BOTH MEASURED AT THE INPUT TO THE LIMITER IN A LIMITER-DISCRIMINATOR DEMODULATOR AND MEASURED IN A BANDWIDTH EQUIVALENT TO THE SUM OF THE BANDWIDTHS OF THE TWO FILTERS IN A DUAL-FILTER DEMODULATOR. MODULATION INDEX IS ASSUMED TO BE NOT LESS THAN UNITY, AND NO LOW-PASS FILTER IS USED BEFORE THE DECISION-MAKING CIRCUIT.)

APPENDIX B

TABULATION OF THE THEORETICAL RELIABILITY OF THE REFERENCE CIRCUIT

Tabulation of the theoretical reliability of the reference circuit as a function of time and distance includes the optimum aeronautical channel (frequency) and the receiving terminal.

Table B-1. North Atlantic Path (Shannon-New York) Pages 58-68.

Table B-2. North Pacific Path (Honolulu-San Francisco) Pages 69-77.

TABLE B-1. THEORETICAL RELIABILITY -- NORTH ATLANTIC PATH

RELIABILITY TABLE SHANNON TO NEW YORK PATH

			SOLAR ACTIVITY LEVEL					
			SSN = 10			SSN = 110		
MONTH	DISTANCE	TIME	TERMINAL	FREQ	REL	TERMINAL	FREQ	REL
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
MAR	200	2	NEW YORK	3.0	.98	NEW YORK	3.0	.95
		4	NEW YORK	3.0	.92	NEW YORK	3.0	.89
		6	NEW YORK	3.0	.82	NEW YORK	3.0	.84
		8	NEW YORK	3.0	.79	NEW YORK	3.0	.88
		10	NEW YORK	3.0	.85	NEW YORK	3.0	.92
		12	NEW YORK	3.0	.96	NEW YORK	4.7	.95
		14	NEW YORK	4.7	.89	NEW YORK	6.6	.91
		16	NEW YORK	4.7	.73	NEW YORK	6.6	.81
		18	NEW YORK	3.5	.76	NEW YORK	8.9	.83
		20	NEW YORK	4.7	.91	NEW YORK	6.6	.95
		22	NEW YORK	3.5	.96	NEW YORK	4.7	.97
		24	NEW YORK	3.0	.98	NEW YORK	4.7	.98
	500	2	NEW YORK	3.0	.99	NEW YORK	4.7	.99
		4	NEW YORK	3.0	.97	NEW YORK	4.7	.98
		6	NEW YORK	3.0	.93	NEW YORK	4.7	.95
		8	NEW YORK	3.0	.94	NEW YORK	3.5	.96
		10	NEW YORK	3.0	.97	NEW YORK	3.5	.98
		12	NEW YORK	3.0	.99	NEW YORK	5.6	.95
		14	NEW YORK	5.6	.94	NEW YORK	8.9	.87
		16	NEW YORK	6.6	.90	NEW YORK	8.9	.82
		18	NEW YORK	5.6	.92	NEW YORK	8.9	.84
		20	NEW YORK	5.6	.97	NEW YORK	8.9	.94
		22	NEW YORK	3.5	.99	NEW YORK	6.6	.96
		24	NEW YORK	3.0	.99	NEW YORK	4.7	.97
	1000	2	NEW YORK	3.0	.95	NEW YORK	6.6	.97
		4	NEW YORK	3.0	.92	NEW YORK	5.6	.93
		6	NEW YORK	3.0	.88	NEW YORK	5.6	.92
		8	NEW YORK	3.0	.94	NEW YORK	4.7	.94
		10	NEW YORK	3.0	.94	NEW YORK	3.5	.93
		12	NEW YORK	5.6	.98	NEW YORK	6.6	.90
		14	NEW YORK	8.9	.93	NEW YORK	11.3	.88
		16	NEW YORK	8.9	.97	NEW YORK	13.3	.89
		18	NEW YORK	8.9	.90	NEW YORK	11.3	.88
		20	NEW YORK	8.9	.96	NEW YORK	11.3	.84
		22	NEW YORK	5.6	.93	NEW YORK	11.3	.84
		24	NEW YORK	5.6	.97	NEW YORK	8.9	.96
	1500	2	NEW YORK	4.7	.89	NEW YORK	8.9	.94
		4	NEW YORK	4.7	.86	NEW YORK	8.9	.89
		6	NEW YORK	4.7	.81	NEW YORK	6.6	.98
		8	NEW YORK	3.5	.84	NEW YORK	6.6	.88
		10	NEW YORK	4.7	.93	NEW YORK	4.7	.87
		12	NEW YORK	6.6	.88	NEW YORK	8.9	.82
		14	NEW YORK	11.3	.99	NEW YORK	13.3	.93
		16	NEW YORK	11.3	.83	NEW YORK	18.0	.73
		18	NEW YORK	11.3	.86	NEW YORK	13.3	.90
		20	NEW YORK	8.9	.90	NEW YORK	13.3	.83
		22	NEW YORK	6.6	.86	NEW YORK	13.3	.91
		24	NEW YORK	6.6	.91	NEW YORK	11.3	.96

TABLE B-1. NORTH ATLANTIC PATH (CONT.)

RELIABILITY TABLE SHANNON TO NEW YORK PATH

MONTH	DISTANCE	TIME	SOLAR ACTIVITY LEVEL SSN = 10			SSN = 110		
MONTH	DISTANCE	TIME	TERMINAL	FREQ	REL	TERMINAL	FREQ	REL
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
MAR	2000	2	NEW YORK	6.6	.81	NEW YORK	8.9	.85
		4	NEW YORK	5.6	.77	NEW YORK	8.9	.83
		6	NEW YORK	5.6	.76	NEW YORK	8.9	.83
		8	NEW YORK	4.7	.80	NEW YORK	6.6	.79
		10	NEW YORK	5.6	.86	NEW YORK	8.9	.79
		12	NEW YORK	8.9	.85	NEW YORK	11.3	.69
		14	NEW YORK	13.3	.73	NEW YORK	18.0	.68
		16	NEW YORK	13.3	.71	NEW YORK	18.0	.74
		18	NEW YORK	11.3	.76	NEW YORK	18.0	.74
		20	NEW YORK	11.3	.83	NEW YORK	13.0	.70
		22	NEW YORK	11.3	.79	NEW YORK	13.3	.74
		24	NEW YORK	8.9	.92	NEW YORK	11.3	.89
	2500	2	NEW YORK	8.9	.58	NEW YORK	11.3	.75
		4	NEW YORK	6.6	.49	NEW YORK	11.3	.74
		6	SHANNON	6.6	.60	NEW YORK	8.9	.73
		8	NEW YORK	6.6	.59	NEW YORK	8.9	.63
		10	NEW YORK	8.9	.57	NEW YORK	11.3	.62
		12	NEW YORK	13.3	.56	NEW YORK	18.0	.58
		14	NEW YORK	13.3	.42	NEW YORK	18.0	.61
		16	NEW YORK	13.3	.40	NEW YORK	18.0	.53
		18	NEW YORK	13.3	.55	NEW YORK	13.0	.63
		20	NEW YORK	11.3	.58	NEW YORK	18.0	.64
		22	NEW YORK	13.3	.64	NEW YORK	18.0	.69
		24	NEW YORK	8.9	.66	NEW YORK	13.3	.74
	3000	2	SHANNON	5.6	.68	SHANNON	8.9	.65
		4	SHANNON	4.7	.68	SHANNON	6.6	.68
		6	SHANNON	3.5	.64	NEW YORK	8.9	.72
		8	SHANNON	6.6	.70	SHANNON	8.9	.7[illegible]
		10	SHANNON	8.9	.59	NEW YORK	11.3	.55
		12	SHANNON	13.3	.59	SHANNON	18.0	.55
		14	SHANNON	13.3	.55	SHANNON	18.0	.61
		16	SHANNON	13.3	.60	SHANNON	18.0	.59
		18	SHANNON	13.3	.56	SHANNON	18.0	.59
		20	SHANNON	8.9	.58	SHANNON	13.3	.62
		22	SHANNON	6.6	.64	SHANNON	8.9	.70
		24	SHANNON	5.6	.70	SHANNON	8.9	.68
	3500	2	SHANNON	3.5	.82	SHANNON	5.6	.81
		4	SHANNON	3.5	.79	SHANNON	5.6	.77
		6	SHANNON	3.5	.79	SHANNON	4.7	.73
		8	SHANNON	5.6	.73	SHANNON	6.6	.67
		10	SHANNON	8.9	.73	SHANNON	11.3	.70
		12	SHANNON	11.3	.70	SHANNON	13.3	.69
		14	SHANNON	11.3	.70	SHANNON	13.3	.64
		16	SHANNON	11.3	.69	SHANNON	13.3	.71
		18	SHANNON	8.9	.62	SHANNON	13.3	.62
		20	SHANNON	6.6	.74	SHANNON	8.9	.77
		22	SHANNON	5.6	.75	SHANNON	6.6	.77
		24	SHANNON	4.7	.79	SHANNON	5.6	.76

TABLE B-1. NORTH ATLANTIC PATH (CONT.)

RELIABILITY TABLE   SHANNON TO NEW YORK PATH

			SOLAR ACTIVITY LEVEL SSN = 10			SSN = 110		
MONTH	DISTANCE	TIME	TERMINAL	FREQ	REL	TERMINAL	FREQ	REL
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
MAR	4000	2	SHANNON	3.0	.89	SHANNON	4.7	.88
		4	SHANNON	3.0	.89	SHANNON	3.5	.87
		6	SHANNON	3.0	.92	SHANNON	3.5	.81
		8	SHANNON	4.7	.81	SHANNON	6.6	.81
		10	SHANNON	6.6	.79	SHANNON	8.9	.70
		12	SHANNON	8.9	.79	SHANNON	11.3	.77
		14	SHANNON	8.9	.77	SHANNON	11.3	.76
		16	SHANNON	8.9	.75	SHANNON	11.3	.70
		18	SHANNON	5.6	.69	SHANNON	8.9	.67
		20	SHANNON	5.6	.83	SHANNON	6.6	.85
		22	SHANNON	3.5	.82	SHANNON	4.7	.84
		24	SHANNON	3.0	.86	SHANNON	4.7	.84
	4500	2	SHANNON	3.0	.88	SHANNON	3.0	.93
		4	SHANNON	3.0	.81	SHANNON	3.0	.94
		6	SHANNON	3.0	.78	SHANNON	3.0	.83
		8	SHANNON	3.5	.83	SHANNON	5.6	.71
		10	SHANNON	4.7	.72	SHANNON	6.6	.67
		12	SHANNON	5.6	.70	SHANNON	8.9	.70
		14	SHANNON	5.6	.66	SHANNON	8.9	.68
		16	SHANNON	4.7	.73	SHANNON	8.9	.75
		18	SHANNON	5.6	.73	SHANNON	6.6	.72
		20	SHANNON	3.5	.91	SHANNON	4.7	.81
		22	SHANNON	3.0	.88	SHANNON	3.5	.89
		24	SHANNON	3.0	.86	SHANNON	3.0	.90
	4745	2	SHANNON	3.0	.73	SHANNON	3.0	.81
		4	SHANNON	3.0	.62	SHANNON	3.0	.83
		6	SHANNON	3.0	.65	SHANNON	3.0	.75
		8	SHANNON	3.5	.71	SHANNON	4.7	.70
		10	SHANNON	4.7	.66	SHANNON	6.6	.70
		12	SHANNON	4.7	.68	SHANNON	6.6	.70
		14	SHANNON	4.7	.65	SHANNON	6.6	.69
		16	SHANNON	4.7	.75	SHANNON	5.6	.79
		18	SHANNON	3.5	.74	SHANNON	5.6	.75
		20	SHANNON	3.0	.82	SHANNON	3.5	.81
		22	SHANNON	3.0	.82	SHANNON	3.0	.79
		24	SHANNON	3.0	.75	SHANNON	3.0	.78
JUN	200	2	NEW YORK	3.0	.98	NEW YORK	4.7	.98
		4	NEW YORK	3.0	.97	NEW YORK	4.7	.96
		6	NEW YORK	3.0	.75	NEW YORK	3.5	.79
		8	NEW YORK	3.0	.77	NEW YORK	3.0	.87
		10	NEW YORK	3.0	.97	NEW YORK	3.5	.94
		12	NEW YORK	3.0	.98	NEW YORK	3.5	.91
		14	NEW YORK	3.5	.94	NEW YORK	5.6	.74
		16	NEW YORK	4.7	.92	NEW YORK	5.6	.65
		18	NEW YORK	4.7	.90	NEW YORK	5.6	.63
		20	NEW YORK	3.5	.92	NEW YORK	5.6	.74
		22	NEW YORK	4.7	.95	NEW YORK	5.6	.85
		24	NEW YORK	4.7	.98	NEW YORK	4.7	.94

TABLE B-1. NORTH ATLANTIC PATH (CONT.)

RELIABILITY TABLE SHANNON TO NEW YORK PATH

			SOLAR ACTIVITY LEVEL					
			SSN = 10			SSN = 110		
MONTH	DISTANCE	TIME	TERMINAL	FREQ	REL	TERMINAL	FREQ	REL
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
JUN	500	2	NEW YORK	4.7	1.00	NEW YORK	4.7	.99
		4	NEW YORK	3.0	.98	NEW YORK	4.7	.98
		6	NEW YORK	3.0	.90	NEW YORK	4.7	.88
		8	NEW YORK	3.0	.95	NEW YORK	3.5	.94
		10	NEW YORK	3.0	.99	NEW YORK	3.5	.99
		12	NEW YORK	4.7	.99	NEW YORK	5.6	.97
		14	NEW YORK	5.6	.97	NEW YORK	6.6	.92
		16	NEW YORK	5.6	.96	NEW YORK	6.6	.87
		18	NEW YORK	5.6	.96	NEW YORK	6.6	.87
		20	NEW YORK	5.6	.98	NEW YORK	6.6	.91
		22	NEW YORK	4.7	.97	NEW YORK	5.6	.93
		24	NEW YORK	5.6	.98	NEW YORK	6.6	.98
	1000	2	NEW YORK	6.6	.98	NEW YORK	8.9	.98
		4	NEW YORK	4.7	.93	NEW YORK	6.6	.95
		6	NEW YORK	4.7	.91	NEW YORK	5.6	.89
		8	NEW YORK	3.0	.93	NEW YORK	3.5	.94
		10	NEW YORK	5.6	.98	NEW YORK	6.6	.95
		12	NEW YORK	6.6	.95	NEW YORK	8.9	.92
		14	NEW YORK	8.9	.89	NEW YORK	8.9	.90
		16	NEW YORK	8.9	.88	NEW YORK	11.3	.84
		18	NEW YORK	8.9	.88	NEW YORK	11.3	.82
		20	NEW YORK	8.9	.89	NEW YORK	8.9	.90
		22	NEW YORK	6.6	.93	NEW YORK	8.9	.93
		24	NEW YORK	8.9	.95	NEW YORK	8.9	.95
	1500	2	NEW YORK	8.9	.96	NEW YORK	11.3	.96
		4	NEW YORK	6.6	.89	NEW YORK	8.9	.93
		6	NEW YORK	5.6	.82	NEW YORK	6.6	.86
		8	NEW YORK	4.7	.95	NEW YORK	4.7	.91
		10	NEW YORK	6.6	.96	NEW YORK	8.9	.91
		12	NEW YORK	8.9	.93	NEW YORK	11.3	.90
		14	NEW YORK	11.3	.90	NEW YORK	13.3	.86
		16	NEW YORK	11.3	.91	NEW YORK	11.3	.74
		18	NEW YORK	11.3	.90	NEW YORK	11.3	.76
		20	NEW YORK	8.9	.93	NEW YORK	11.3	.91
		22	NEW YORK	8.9	.91	NEW YORK	11.3	.93
		24	NEW YORK	11.3	.93	NEW YORK	11.3	.94
	2000	2	NEW YORK	8.9	.90	NEW YORK	11.3	.93
		4	NEW YORK	6.6	.80	NEW YORK	11.3	.87
		6	NEW YORK	6.6	.79	NEW YORK	8.9	.86
		8	NEW YORK	5.6	.91	NEW YORK	6.6	.86
		10	NEW YORK	8.9	.92	NEW YORK	8.9	.89
		12	NEW YORK	11.3	.83	NEW YORK	13.3	.81
		14	NEW YORK	11.3	.83	NEW YORK	13.3	.78
		16	NEW YORK	13.3	.78	NEW YORK	18.0	.73
		18	NEW YORK	13.3	.74	NEW YORK	13.3	.73
		20	NEW YORK	11.3	.78	NEW YORK	13.3	.7[illegible]
		22	NEW YORK	11.3	.92	NEW YORK	13.3	.87
		24	NEW YORK	11.3	.88	NEW YORK	13.3	.91

TABLE B-1. NORTH ATLANTIC PATH (CONT.)

RELIABILITY TABLE SHANNON TO NEW YORK PATH

			SOLAR ACTIVITY LEVEL SSN = 10			SSN = 110		
MONTH	DISTANCE	TIME	TERMINAL	FREQ	REL	TERMINAL	FREQ	REL
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
JUN	2500	2	NEW YORK	11.3	.72	NEW YORK	13.3	.85
		4	NEW YORK	8.9	.62	NEW YORK	11.3	.82
		6	NEW YORK	8.9	.56	NEW YORK	11.3	.73
		8	NEW YORK	8.9	.66	NEW YORK	11.3	.61
		10	NEW YORK	11.3	.65	NEW YORK	11.3	.70
		12	NEW YORK	13.3	.67	SHANNON	18.0	.54
		14	NEW YORK	13.3	.53	NEW YORK	18.0	.35
		16	SHANNON	13.3	.43	SHANNON	18.0	.46
		18	NEW YORK	13.3	.50	SHANNON	13.3	.37
		20	NEW YORK	13.3	.62	NEW YORK	13.3	.46
		22	NEW YORK	11.3	.59	NEW YORK	18.0	.68
		24	NEW YORK	13.3	.79	NEW YORK	13.3	.75
	3000	2	SHANNON	6.6	.69	NEW YORK	13.3	.74
		4	SHANNON	6.6	.69	SHANNON	8.9	.74
		6	SHANNON	6.6	.75	SHANNON	8.9	.76
		8	SHANNON	11.3	.72	SHANNON	11.3	.72
		10	SHANNON	11.3	.74	SHANNON	13.3	.73
		12	SHANNON	13.3	.79	SHANNON	13.3	.73
		14	SHANNON	11.3	.71	SHANNON	13.3	.70
		16	SHANNON	13.3	.70	SHANNON	13.3	.68
		18	SHANNON	11.3	.72	SHANNON	13.3	.70
		20	SHANNON	13.3	.63	SHANNON	11.3	.70
		22	SHANNON	13.3	.66	SHANNON	13.3	.70
		24	SHANNON	8.9	.69	SHANNON	11.3	.76
	3500	2	SHANNON	5.6	.87	SHANNON	8.9	.88
		4	SHANNON	6.6	.85	SHANNON	6.6	.82
		6	SHANNON	6.6	.85	SHANNON	8.9	.81
		8	SHANNON	8.9	.87	SHANNON	11.3	.80
		10	SHANNON	11.3	.80	SHANNON	11.3	.77
		12	SHANNON	11.3	.87	SHANNON	13.3	.83
		14	SHANNON	11.3	.78	SHANNON	13.3	.77
		16	SHANNON	11.3	.77	SHANNON	13.3	.74
		18	SHANNON	8.9	.82	SHANNON	11.3	.7[illegible]
		20	SHANNON	11.3	.71	SHANNON	11.3	.73
		22	SHANNON	8.9	.75	SHANNON	11.3	.78
		24	SHANNON	6.6	.80	SHANNON	8.9	.83
	4000	2	SHANNON	3.5	.92	SHANNON	5.6	.94
		4	SHANNON	4.7	.92	SHANNON	4.7	.90
		6	SHANNON	5.6	.89	SHANNON	6.6	.87
		8	SHANNON	6.6	.90	SHANNON	8.9	.84
		10	SHANNON	8.9	.82	SHANNON	8.9	.82
		12	SHANNON	8.9	.90	SHANNON	8.9	.90
		14	SHANNON	8.9	.81	SHANNON	11.3	.76
		16	SHANNON	8.9	.79	SHANNON	8.9	.79
		18	SHANNON	6.6	.87	SHANNON	8.9	.82
		20	SHANNON	5.6	.82	SHANNON	8.9	.82
		22	SHANNON	6.6	.84	SHANNON	8.9	.84
		24	SHANNON	4.7	.88	SHANNON	5.6	.90

TABLE B-1. NORTH ATLANTIC PATH (CONT.)

RELIABILITY TABLE   SHANNON TO NEW YORK PATH

			SOLAR ACTIVITY LEVEL					
			SSN = 10			SSN = 110		
MONTH	DISTANCE	TIME	TERMINAL	FREQ	REL	TERMINAL	FREQ	REL
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
JUN	4500	2	SHANNON	3.0	.97	SHANNON	3.5	.97
		4	SHANNON	3.0	.96	SHANNON	3.5	.94
		6	SHANNON	3.5	.90	SHANNON	4.7	.85
		8	SHANNON	4.7	.90	SHANNON	5.6	.84
		10	SHANNON	5.6	.89	SHANNON	6.6	.80
		12	SHANNON	5.6	.94	SHANNON	6.6	.82
		14	SHANNON	5.6	.85	SHANNON	6.6	.76
		16	SHANNON	5.6	.85	SHANNON	6.6	.77
		18	SHANNON	4.7	.89	SHANNON	5.6	.82
		20	SHANNON	5.6	.91	SHANNON	5.6	.88
		22	SHANNON	4.7	.92	SHANNON	5.6	.91
		24	SHANNON	3.0	.94	SHANNON	4.7	.94
	4745	2	SHANNON	3.0	.96	SHANNON	3.0	.90
		4	SHANNON	3.0	.97	SHANNON	3.5	.91
		6	SHANNON	3.5	.89	SHANNON	4.7	.77
		8	SHANNON	3.0	.87	SHANNON	5.6	.72
		10	SHANNON	4.7	.81	SHANNON	5.6	.65
		12	SHANNON	3.5	.84	SHANNON	5.6	.62
		14	SHANNON	3.5	.73	SHANNON	5.6	.58
		16	SHANNON	3.5	.78	SHANNON	5.6	.61
		18	SHANNON	4.7	.84	SHANNON	5.6	.74
		20	SHANNON	4.7	.93	SHANNON	4.7	.81
		22	SHANNON	3.5	.93	SHANNON	4.7	.80
		24	SHANNON	3.0	.95	SHANNON	3.5	.84
SEP	200	2	NEW YORK	3.0	.97	NEW YORK	3.5	.96
		4	NEW YORK	3.0	.87	NEW YORK	3.5	.91
		6	NEW YORK	3.0	.74	NEW YORK	3.5	.88
		8	NEW YORK	3.0	.64	NEW YORK	3.0	.98
		10	NEW YORK	3.0	.84	NEW YORK	3.0	.89
		12	NEW YORK	3.5	.96	NEW YORK	4.7	.93
		14	NEW YORK	4.7	.95	NEW YORK	6.6	.95
		16	NEW YORK	4.7	.71	NEW YORK	6.6	.72
		18	NEW YORK	3.5	.81	NEW YORK	6.6	.76
		20	NEW YORK	3.0	.92	NEW YORK	6.6	.93
		22	NEW YORK	3.5	.96	NEW YORK	5.6	.96
		24	NEW YORK	3.0	.97	NEW YORK	4.7	.97
	500	2	NEW YORK	3.0	.98	NEW YORK	4.7	.99
		4	NEW YORK	3.0	.95	NEW YORK	4.7	.98
		6	NEW YORK	3.0	.90	NEW YORK	4.7	.96
		8	NEW YORK	3.0	.94	NEW YORK	3.5	.95
		10	NEW YORK	3.0	.95	NEW YORK	3.5	.95
		12	NEW YORK	3.5	.99	NEW YORK	6.6	.96
		14	NEW YORK	5.6	.95	NEW YORK	6.6	.81
		16	NEW YORK	5.6	.88	NEW YORK	5.9	.75
		18	NEW YORK	5.6	.93	NEW YORK	8.9	.77
		20	NEW YORK	4.7	.98	NEW YORK	6.6	.91
		22	NEW YORK	4.7	.99	NEW YORK	5.6	.97
		24	NEW YORK	4.7	.99	NEW YORK	5.6	.9[illegible]

TABLE B-1. NORTH ATLANTIC PATH (CONT.)

RELIABILITY TABLE SHANNON TO NEW YORK PATH

			SOLAR ACTIVITY LEVEL SSN = 10			SSN = 110		
MONTH (1)	DISTANCE (2)	TIME (3)	TERMINAL (4)	FREQ (5)	REL (6)	TERMINAL (7)	FREQ (8)	REL (9)
SEP	1000	2	NEW YORK	3.5	.94	NEW YORK	6.6	.97
		4	NEW YORK	3.0	.91	NEW YORK	5.6	.94
		6	NEW YORK	3.0	.89	NEW YORK	5.6	.94
		8	NEW YORK	3.0	.90	NEW YORK	4.7	.93
		10	NEW YORK	3.5	.92	NEW YORK	4.7	.91
		12	NEW YORK	6.6	.97	NEW YORK	8.9	.96
		14	NEW YORK	8.9	.88	NEW YORK	11.3	.90
		16	NEW YORK	8.9	.82	NEW YORK	11.3	.84
		18	NEW YORK	8.9	.84	NEW YORK	11.3	.30
		20	NEW YORK	6.6	.38	NEW YORK	11.3	.90
		22	NEW YORK	6.6	.92	NEW YORK	8.9	.94
		24	NEW YORK	5.6	.95	NEW YORK	8.9	.98
	1500	2	NEW YORK	5.6	.90	NEW YORK	8.9	.35
		4	NEW YORK	4.7	.37	NEW YORK	8.9	.92
		6	NEW YORK	4.7	.82	NEW YORK	6.6	.92
		8	NEW YORK	3.0	.82	NEW YORK	6.6	.88
		10	NEW YORK	4.7	.91	NEW YORK	6.6	.37
		12	NEW YORK	8.9	.93	NEW YORK	11.3	.33
		14	NEW YORK	11.3	.36	NEW YORK	13.3	.83
		16	NEW YORK	11.3	.78	NEW YORK	13.3	.80
		18	NEW YORK	11.3	.33	NEW YORK	13.3	.86
		20	NEW YORK	8.9	.31	NEW YORK	13.3	.88
		22	NEW YORK	8.9	.37	NEW YORK	13.3	.92
		24	NEW YORK	6.6	.90	NEW YORK	11.3	.97
	2000	2	NEW YORK	6.6	.82	NEW YORK	8.9	.87
		4	NEW YORK	5.6	.31	NEW YORK	8.9	.86
		6	NEW YORK	4.7	.75	NEW YORK	8.9	.84
		8	NEW YORK	3.0	.75	NEW YORK	6.6	.77
		10	NEW YORK	5.6	.84	NEW YORK	8.9	.88
		12	NEW YORK	11.3	.35	NEW YORK	13.3	.80
		14	NEW YORK	13.3	.75	NEW YORK	18.0	.73
		16	NEW YORK	13.3	.73	NEW YORK	18.0	.71
		18	NEW YORK	11.3	.75	NEW YORK	18.0	.70
		20	NEW YORK	11.3	.33	NEW YORK	13.3	.79
		22	NEW YORK	11.3	.83	NEW YORK	13.3	.84
		24	NEW YORK	8.9	.95	NEW YORK	11.3	.90
	2500	2	NEW YORK	6.6	.71	NEW YORK	11.3	.79
		4	NEW YORK	6.6	.58	NEW YORK	8.9	.76
		6	NEW YORK	6.6	.61	NEW YORK	8.9	.77
		8	NEW YORK	5.6	.54	NEW YORK	8.9	.71
		10	NEW YORK	6.6	.62	NEW YORK	11.3	.64
		12	NEW YORK	11.3	.63	NEW YORK	18.0	.55
		14	NEW YORK	13.3	.50	NEW YORK	18.0	.53
		16	SHANNON	13.3	.50	SHANNON	18.0	.54
		18	NEW YORK	13.3	.55	NEW YORK	18.0	.56
		20	NEW YORK	11.3	.68	NEW YORK	18.0	.61
		22	NEW YORK	13.3	.66	NEW YORK	18.0	.67
		24	NEW YORK	11.3	.70	NEW YORK	13.3	.82

TABLE B-1. NORTH ATLANTIC PATH (CONT.)

RELIABILITY TABLE SHANNON TO NEW YORK PATH

MONTH (1)	DISTANCE (2)	TIME (3)	SOLAR ACTIVITY LEVEL SSN = 10 TERMINAL (4)	FREQ (5)	REL (6)	SSN = 110 TERMINAL (7)	FREQ (8)	REL (9)
SEP	3000	2	SHANNON	5.6	.69	EITHER	11.3	.68
		4	SHANNON	4.7	.75	SHANNON	6.6	.74
		6	SHANNON	4.7	.69	NEW YORK	8.9	.65
		8	SHANNON	6.6	.68	SHANNON	8.9	.70
		10	SHANNON	11.3	.60	SHANNON	13.3	.62
		12	SHANNON	13.3	.60	SHANNON	18.0	.59
		14	SHANNON	13.3	.60	SHANNON	18.0	.61
		16	SHANNON	11.3	.67	SHANNON	13.3	.65
		18	SHANNON	11.3	.58	SHANNON	18.0	.59
		20	SHANNON	11.3	.60	SHANNON	13.3	.64
		22	SHANNON	8.9	.65	SHANNON	11.3	.70
		24	SHANNON	6.6	.68	NEW YORK	13.3	.70
	3500	2	SHANNON	4.7	.93	SHANNON	5.6	.83
		4	SHANNON	3.5	.93	SHANNON	5.6	.82
		6	SHANNON	4.7	.77	SHANNON	5.6	.71
		8	EITHER	3.5	.72	SHANNON	8.9	.72
		10	SHANNON	8.9	.72	SHANNON	11.3	.71
		12	SHANNON	11.3	.69	SHANNON	13.3	.70
		14	SHANNON	11.3	.70	SHANNON	13.3	.71
		16	SHANNON	11.3	.68	SHANNON	11.3	.76
		18	SHANNON	8.9	.65	SHANNON	13.3	.66
		20	SHANNON	8.9	.75	SHANNON	11.3	.78
		22	SHANNON	5.6	.75	SHANNON	8.9	.77
		24	SHANNON	4.7	.78	SHANNON	6.6	.77
	4000	2	SHANNON	3.0	.90	SHANNON	3.5	.90
		4	SHANNON	3.0	.90	SHANNON	4.7	.89
		6	SHANNON	3.5	.84	SHANNON	4.7	.79
		8	SHANNON	5.6	.79	SHANNON	6.6	.74
		10	SHANNON	6.6	.77	SHANNON	8.9	.76
		12	SHANNON	8.9	.75	SHANNON	11.3	.76
		14	SHANNON	8.9	.70	SHANNON	11.3	.76
		16	SHANNON	6.6	.84	SHANNON	8.9	.77
		18	SHANNON	5.6	.73	SHANNON	8.9	.73
		20	SHANNON	5.6	.83	SHANNON	6.6	.84
		22	SHANNON	4.7	.93	SHANNON	5.6	.93
		24	SHANNON	3.0	.96	SHANNON	4.7	.95
	4500	2	SHANNON	3.0	.89	SHANNON	3.0	.95
		4	SHANNON	3.0	.95	SHANNON	3.0	.95
		6	SHANNON	3.0	.90	SHANNON	3.0	.95
		8	SHANNON	3.5	.90	SHANNON	4.7	.77
		10	SHANNON	5.6	.72	SHANNON	6.6	.70
		12	SHANNON	5.6	.79	SHANNON	6.6	.66
		14	SHANNON	5.6	.78	SHANNON	6.6	.63
		16	SHANNON	4.7	.81	SHANNON	6.6	.71
		18	SHANNON	4.7	.80	SHANNON	6.6	.73
		20	SHANNON	3.5	.90	SHANNON	4.7	.91
		22	SHANNON	3.0	.99	SHANNON	3.5	.89
		24	SHANNON	3.0	.98	SHANNON	3.0	.91

TABLE B-1. NORTH ATLANTIC PATH (CONT.)

RELIABILITY TABLE   SHANNON TO NEW YORK PATH

			SOLAR ACTIVITY LEVEL					
			SSN = 10			SSN = 110		
MONTH (1)	DISTANCE (2)	TIME (3)	TERMINAL (4)	FREQ (5)	REL (6)	TERMINAL (7)	FREQ (8)	REL (9)
SEP	4745	2	SHANNON	3.0	.77	SHANNON	3.0	.85
		4	SHANNON	3.0	.62	SHANNON	3.0	.85
		6	SHANNON	3.0	.73	SHANNON	3.0	.76
		8	SHANNON	3.5	.75	SHANNON	4.7	.68
		10	SHANNON	3.0	.66	SHANNON	6.6	.63
		12	SHANNON	3.5	.64	SHANNON	6.6	.63
		14	SHANNON	3.5	.63	SHANNON	6.6	.62
		16	SHANNON	3.0	.70	SHANNON	6.6	.72
		18	SHANNON	3.5	.74	SHANNON	4.7	.73
		20	SHANNON	3.0	.86	SHANNON	4.7	.82
		22	SHANNON	3.0	.88	SHANNON	3.0	.82
		24	SHANNON	3.0	.81	SHANNON	3.0	.84
DEC	200	2	NEW YORK	3.0	.93	NEW YORK	3.0	.98
		4	NEW YORK	3.0	.88	NEW YORK	3.0	.96
		6	NEW YORK	3.0	.97	NEW YORK	3.0	.96
		8	NEW YORK	3.0	.99	NEW YORK	3.0	.96
		10	NEW YORK	3.0	.94	NEW YORK	3.0	.99
		12	NEW YORK	3.0	1.00	NEW YORK	4.7	.98
		14	NEW YORK	4.7	.98	NEW YORK	5.6	.98
		16	NEW YORK	5.6	.98	NEW YORK	8.9	.99
		18	NEW YORK	5.6	.98	NEW YORK	8.9	.99
		20	NEW YORK	4.7	.99	NEW YORK	5.6	.99
		22	NEW YORK	3.0	.99	NEW YORK	4.7	.99
		24	NEW YORK	3.0	.99	NEW YORK	3.0	.98
	500	2	NEW YORK	3.0	.98	NEW YORK	3.0	.99
		4	NEW YORK	3.0	.96	NEW YORK	3.0	.99
		6	NEW YORK	3.0	.99	NEW YORK	3.5	.99
		8	NEW YORK	3.0	.99	NEW YORK	3.0	.99
		10	NEW YORK	3.0	.99	NEW YORK	3.0	.99
		12	NEW YORK	3.5	1.00	NEW YORK	4.7	.99
		14	NEW YORK	5.6	.99	NEW YORK	8.9	.97
		16	NEW YORK	6.6	.95	NEW YORK	11.3	.99
		18	NEW YORK	6.6	.96	NEW YORK	11.3	.98
		20	NEW YORK	6.6	.99	NEW YORK	8.9	.99
		22	NEW YORK	4.7	1.00	NEW YORK	5.6	.98
		24	NEW YORK	3.0	1.00	NEW YORK	3.5	.99
	1000	2	NEW YORK	3.0	.97	NEW YORK	6.6	.99
		4	NEW YORK	3.0	.96	NEW YORK	4.7	.99
		6	NEW YORK	3.0	.98	NEW YORK	5.6	.99
		8	NEW YORK	3.0	.98	NEW YORK	4.7	.98
		10	NEW YORK	3.0	.98	NEW YORK	4.7	.97
		12	NEW YORK	5.6	.98	NEW YORK	3.9	.99
		14	NEW YORK	8.9	.97	NEW YORK	13.3	.91
		16	NEW YORK	11.3	.93	NEW YORK	18.0	.96
		18	NEW YORK	11.3	.94	NEW YORK	13.3	.93
		20	NEW YORK	8.9	.98	NEW YORK	11.3	.97
		22	NEW YORK	6.6	.99	NEW YORK	11.3	.97
		24	NEW YORK	3.5	.99	NEW YORK	8.9	.99

TABLE B-1. NORTH ATLANTIC PATH (CONT.)

RELIABILITY TABLE SHANNON TO NEW YORK PATH

			SOLAR ACTIVITY LEVEL					
			SSN = 10			SSN = 110		
MONTH	DISTANCE	TIME	TERMINAL	FREQ	REL	TERMINAL	FREQ	REL
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
DEC	1500	2	NEW YORK	4.7	.90	NEW YORK	8.9	.98
		4	NEW YORK	4.7	.92	NEW YORK	6.6	.96
		6	NEW YORK	4.7	.96	NEW YORK	8.9	.98
		8	NEW YORK	4.7	.97	NEW YORK	6.6	.96
		10	NEW YORK	4.7	.95	NEW YORK	6.6	.95
		12	NEW YORK	8.9	.93	NEW YORK	11.3	.96
		14	NEW YORK	13.3	.95	NEW YORK	18.0	.93
		16	NEW YORK	13.3	.83	NEW YORK	18.0	.90
		18	NEW YORK	11.3	.91	NEW YORK	18.0	.93
		20	NEW YORK	11.3	.91	NEW YORK	18.0	.93
		22	NEW YORK	8.9	.97	NEW YORK	13.3	.95
		24	NEW YORK	4.7	.97	NEW YORK	11.3	.98
	2000	2	NEW YORK	5.6	.83	NEW YORK	8.9	.94
		4	NEW YORK	5.6	.86	NEW YORK	8.9	.94
		6	NEW YORK	5.6	.91	NEW YORK	8.9	.94
		8	NEW YORK	5.6	.91	NEW YORK	8.9	.87
		10	NEW YORK	5.6	.89	NEW YORK	6.6	.84
		12	NEW YORK	8.9	.84	NEW YORK	13.3	.89
		14	NEW YORK	13.3	.82	NEW YORK	18.0	.85
		16	NEW YORK	18.0	.80	NEW YORK	18.0	.80
		18	NEW YORK	18.0	.77	NEW YORK	18.0	.86
		20	NEW YORK	13.3	.84	NEW YORK	18.0	.86
		22	NEW YORK	8.9	.90	NEW YORK	13.3	.91
		24	NEW YORK	5.6	.90	NEW YORK	11.3	.96
	2500	2	NEW YORK	6.6	.69	NEW YORK	11.3	.87
		4	NEW YORK	6.6	.69	NEW YORK	11.3	.83
		6	NEW YORK	6.6	.72	NEW YORK	11.3	.87
		8	NEW YORK	6.6	.72	NEW YORK	8.9	.80
		10	NEW YORK	6.6	.67	NEW YORK	8.9	.77
		12	NEW YORK	11.3	.71	SHANNON	18.0	.79
		14	NEW YORK	18.0	.72	NEW YORK	18.0	.79
		16	NEW YORK	18.0	.74	SHANNON	18.0	.83
		18	NEW YORK	18.0	.76	NEW YORK	18.0	.91
		20	NEW YORK	13.3	.73	NEW YORK	18.0	.82
		22	NEW YORK	8.9	.73	NEW YORK	18.0	.94
		24	NEW YORK	6.6	.62	NEW YORK	13.3	.89
	3000	2	SHANNON	4.7	.85	SHANNON	6.6	.87
		4	SHANNON	4.7	.83	SHANNON	6.6	.85
		6	SHANNON	4.7	.80	SHANNON	5.6	.80
		8	SHANNON	5.6	.77	SHANNON	8.9	.85
		10	NEW YORK	4.7	.73	SHANNON	13.3	.73
		12	SHANNON	11.3	.97	SHANNON	18.0	.84
		14	SHANNON	11.3	.78	SHANNON	18.0	.83
		16	SHANNON	11.3	.80	SHANNON	18.0	.89
		18	SHANNON	8.9	.82	SHANNON	13.3	.79
		20	SHANNON	5.6	.78	SHANNON	11.3	.90
		22	SHANNON	4.7	.80	SHANNON	8.9	.85
		24	SHANNON	4.7	.85	SHANNON	6.6	.90

TABLE B-1. NORTH ATLANTIC PATH (CONT.)

RELIABILITY TABLE SHANNON TO NEW YORK PATH

			SOLAR ACTIVITY LEVEL					
			SSN = 10			SSN = 110		
MONTH (1)	DISTANCE (2)	TIME (3)	TERMINAL (4)	FREQ (5)	REL (6)	TERMINAL (7)	FREQ (8)	REL (9)
DEC	3500	2	SHANNON	3.5	.91	SHANNON	5.6	.94
		4	SHANNON	3.5	.91	SHANNON	6.6	.94
		6	SHANNON	3.0	.89	SHANNON	4.7	.89
		8	SHANNON	3.5	.78	SHANNON	6.6	.8[illegible]
		10	SHANNON	6.6	.88	SHANNON	13.3	.93
		12	SHANNON	8.9	.93	SHANNON	18.0	.91
		14	SHANNON	11.3	.86	SHANNON	18.0	.94
		16	SHANNON	8.9	.92	SHANNON	18.0	.94
		18	SHANNON	6.6	.91	SHANNON	11.3	.88
		20	SHANNON	3.5	.86	SHANNON	3.9	.34
		22	SHANNON	3.5	.88	SHANNON	5.6	.93
		24	SHANNON	3.5	.31	SHANNON	4.7	.95
	4000	2	SHANNON	3.0	.96	SHANNON	4.7	.97
		4	SHANNON	3.0	.97	SHANNON	4.7	.97
		6	SHANNON	3.0	.92	SHANNON	3.0	.95
		8	SHANNON	3.0	.90	SHANNON	6.6	.92
		10	SHANNON	5.6	.95	SHANNON	11.3	.85
		12	SHANNON	8.9	.93	SHANNON	13.3	.92
		14	SHANNON	8.9	.94	SHANNON	13.3	.95
		16	SHANNON	5.6	.97	SHANNON	11.3	.96
		18	SHANNON	4.7	.97	SHANNON	8.9	.94
		20	SHANNON	3.0	.95	SHANNON	5.6	.97
		22	SHANNON	3.0	.34	SHANNON	4.7	.97
		24	SHANNON	3.3	.96	SHANNON	3.5	.98
	4500	2	SHANNON	3.0	.96	SHANNON	3.0	.99
		4	SHANNON	3.0	.95	SHANNON	3.0	.99
		6	SHANNON	3.0	.74	SHANNON	3.0	.93
		8	SHANNON	3.0	.96	SHANNON	4.7	.92
		10	SHANNON	3.5	.93	SHANNON	6.6	.87
		12	SHANNON	5.6	.94	SHANNON	8.9	.96
		14	SHANNON	5.6	.96	SHANNON	6.9	.98
		16	SHANNON	4.7	.99	SHANNON	8.9	.99
		18	SHANNON	3.0	.99	SHANNON	5.6	.96
		20	SHANNON	3.0	.86	SHANNON	3.5	.99
		22	SHANNON	3.0	.44	SHANNON	3.5	.99
		24	SHANNON	3.0	.94	SHANNON	3.0	.99
	4745	2	SHANNON	3.0	.37	SHANNON	3.0	.92
		4	SHANNON	3.0	.81	SHANNON	3.0	.91
		6	SHANNON	3.0	.43	SHANNON	3.0	.78
		8	SHANNON	3.0	.90	SHANNON	3.5	.88
		10	SHANNON	3.5	.87	SHANNON	5.6	.91
		12	SHANNON	4.7	.93	SHANNON	6.6	.97
		14	SHANNON	4.7	.97	SHANNON	6.6	.99
		16	SHANNON	3.5	.98	SHANNON	4.7	.39
		18	SHANNON	3.0	.48	SHANNON	4.7	.96
		20	SHANNON	3.0	.68	SHANNON	3.0	.95
		22	SHANNON	3.0	.61	SHANNON	3.0	.95
		24	SHANNON	3.0	.84	SHANNON	3.0	.35

TABLE B-2. THEORETICAL RELIABILITY -- NORTH PACIFIC PATH

RELIABILITY TABLE HONOLULU TO SAN FRAN PATH

			SOLAR ACTIVITY LEVEL SSN = 10			SSN = 110		
MONTH	DISTANCE	TIME	TERMINAL	FREQ	REL	TERMINAL	FREQ	REL
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
MAR	200	2	SAN FRAN	3.0	.97	SAN FRAN	4.7	.98
		4	SAN FRAN	3.0	.97	SAN FRAN	3.5	.98
		6	SAN FRAN	3.0	.93	SAN FRAN	3.5	.94
		8	SAN FRAN	3.0	.90	SAN FRAN	3.0	.92
		10	SAN FRAN	3.0	.89	SAN FRAN	3.0	.91
		12	SAN FRAN	3.0	.91	SAN FRAN	3.0	.94
		14	SAN FRAN	3.0	.94	SAN FRAN	3.5	.94
		16	SAN FRAN	3.5	.96	SAN FRAN	5.6	.96
		18	SAN FRAN	4.7	.89	SAN FRAN	6.6	.92
		20	SAN FRAN	5.6	.77	SAN FRAN	8.9	.99
		22	SAN FRAN	5.6	.80	SAN FRAN	8.9	.90
		24	SAN FRAN	4.7	.95	SAN FRAN	6.6	.96
	500	2	SAN FRAN	4.7	.97	SAN FRAN	6.6	.97
		4	SAN FRAN	3.0	.99	SAN FRAN	5.6	.97
		6	SAN FRAN	3.0	.99	SAN FRAN	4.7	.95
		8	SAN FRAN	3.0	.98	SAN FRAN	3.0	.95
		10	SAN FRAN	3.0	.98	SAN FRAN	3.0	.90
		12	SAN FRAN	3.0	.99	SAN FRAN	3.5	.92
		14	SAN FRAN	3.0	.99	SAN FRAN	4.7	.92
		16	SAN FRAN	4.7	.99	SAN FRAN	6.6	.93
		18	SAN FRAN	6.6	.95	SAN FRAN	8.9	.92
		20	SAN FRAN	6.6	.86	SAN FRAN	11.3	.82
		22	SAN FRAN	6.6	.89	SAN FRAN	8.9	.94
		24	SAN FRAN	6.6	.94	SAN FRAN	8.9	.95
	1000	2	SAN FRAN	6.6	.96	SAN FRAN	11.3	.93
		4	SAN FRAN	4.7	.97	SAN FRAN	8.9	.94
		6	SAN FRAN	4.7	.97	SAN FRAN	6.6	.98
		8	SAN FRAN	3.5	.96	SAN FRAN	5.6	.97
		10	SAN FRAN	3.5	.94	SAN FRAN	5.6	.92
		12	SAN FRAN	3.5	.95	SAN FRAN	4.7	.88
		14	SAN FRAN	3.5	.96	SAN FRAN	5.6	.89
		16	SAN FRAN	6.6	.99	SAN FRAN	11.3	.91
		18	SAN FRAN	8.9	.97	SAN FRAN	13.3	.90
		20	SAN FRAN	8.9	.88	SAN FRAN	13.3	.95
		22	SAN FRAN	8.9	.92	SAN FRAN	13.3	.93
		24	SAN FRAN	8.9	.98	SAN FRAN	13.3	.92
	1500	2	SAN FRAN	11.3	.90	SAN FRAN	18.0	.91
		4	SAN FRAN	6.6	.91	SAN FRAN	13.3	.92
		6	SAN FRAN	5.6	.93	SAN FRAN	8.9	.94
		8	SAN FRAN	5.6	.91	SAN FRAN	8.9	.95
		10	SAN FRAN	5.6	.99	SAN FRAN	8.9	.94
		12	SAN FRAN	5.6	.89	SAN FRAN	6.6	.81
		14	SAN FRAN	4.7	.87	SAN FRAN	8.9	.92
		16	SAN FRAN	8.9	.96	SAN FRAN	13.3	.96
		18	SAN FRAN	13.3	.96	SAN FRAN	18.0	.96
		20	SAN FRAN	13.3	.99	SAN FRAN	18.0	.94
		22	SAN FRAN	13.3	.89	SAN FRAN	18.0	.92
		24	SAN FRAN	11.3	.96	SAN FRAN	18.0	.90

TABLE B-2. NORTH PACFIC PATH (CONT.)

RELIABILITY TABLE HONOLULU TO SAN FRAN PATH

			SOLAR ACTIVITY LEVEL					
			SSN = 10			SSN = 110		
MONTH	DISTANCE	TIME	TERMINAL	FREQ	REL	TERMINAL	FREQ	REL
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
MAR	2000	2	HONOLULU	18.0	.91	SAN FRAN	18.0	.90
		4	HONOLULU	13.3	.90	HONOLULU	18.0	.92
		6	HONOLULU	8.9	.88	HONOLULU	18.0	.94
		8	HONOLULU	4.7	.86	HONOLULU	13.3	.90
		10	HONOLULU	4.7	.91	HONOLULU	8.9	.87
		12	HONOLULU	5.6	.85	HONOLULU	11.3	.84
		14	HONOLULU	4.7	.78	HONOLULU	8.9	.79
		16	HONOLULU	6.6	.88	SAN FRAN	18.0	.88
		18	HONOLULU	11.3	.91	HONOLULU	18.0	.85
		20	HONOLULU	13.3	.86	HONOLULU	18.0	.77
		22	HONOLULU	18.0	.89	SAN FRAN	18.0	.76
		24	HONOLULU	18.0	.84	SAN FRAN	18.0	.81
	2500	2	HONOLULU	18.0	.97	HONOLULU	18.0	.92
		4	HONOLULU	13.3	.95	HONOLULU	18.0	.96
		6	HONOLULU	6.6	.95	HONOLULU	11.3	.96
		8	HONOLULU	3.5	.93	HONOLULU	8.9	.94
		10	HONOLULU	3.5	.91	HONOLULU	11.3	.92
		12	HONOLULU	4.7	.91	HONOLULU	8.9	.89
		14	HONOLULU	3.5	.88	HONOLULU	4.7	.93
		16	HONOLULU	5.6	.95	HONOLULU	8.9	.88
		18	HONOLULU	8.9	.96	HONOLULU	18.0	.93
		20	HONOLULU	13.3	.96	HONOLULU	18.0	.90
		22	HONOLULU	13.3	.88	HONOLULU	18.0	.87
		24	HONOLULU	18.0	.95	HONOLULU	18.0	.91
	3000	2	HONOLULU	13.3	.98	HONOLULU	18.0	.97
		4	HONOLULU	11.3	.99	HONOLULU	11.3	.96
		6	HONOLULU	4.7	.99	HONOLULU	8.9	.98
		8	HONOLULU	3.5	.98	HONOLULU	8.9	.97
		10	HONOLULU	3.0	.97	HONOLULU	6.6	.95
		12	HONOLULU	3.0	.96	HONOLULU	5.6	.93
		14	HONOLULU	3.0	.96	HONOLULU	4.7	.97
		16	HONOLULU	3.5	.95	HONOLULU	4.7	.95
		18	HONOLULU	8.9	.98	HONOLULU	13.3	.96
		20	HONOLULU	11.3	.97	HONOLULU	13.3	.91
		22	HONOLULU	11.3	.96	HONOLULU	18.0	.94
		24	HONOLULU	13.3	.96	HONOLULU	18.0	.95
	3500	2	HONOLULU	8.9	.98	HONOLULU	11.3	.98
		4	HONOLULU	4.7	.99	HONOLULU	5.6	.98
		6	HONOLULU	3.5	1.00	HONOLULU	6.6	.99
		8	HONOLULU	3.0	.99	HONOLULU	6.6	.98
		10	HONOLULU	3.0	.99	HONOLULU	5.6	.97
		12	HONOLULU	3.0	.99	HONOLULU	3.0	.95
		14	HONOLULU	3.0	.98	HONOLULU	3.0	.96
		16	HONOLULU	3.0	.96	HONOLULU	3.0	.98
		18	HONOLULU	5.6	.99	HONOLULU	8.9	.97
		20	HONOLULU	6.6	.97	HONOLULU	11.3	.97
		22	HONOLULU	8.9	.95	HONOLULU	13.3	.93
		24	HONOLULU	11.3	.97	HONOLULU	13.3	.96

RELIABILITY TABLE HONOLULU TO SAN FRAN PATH

			SOLAR ACTIVITY LEVEL SSN = 10			SSN = 110		
MONTH	DISTANCE	TIME	TERMINAL	FREQ	REL	TERMINAL	FREQ	REL
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
MAR	3643	2	HONOLULU	6.6	.98	HONOLULU	11.3	.99
		4	HONOLULU	4.7	.99	HONOLULU	5.6	.99
		6	HONOLULU	3.0	1.00	HONOLULU	4.7	.99
		8	HONOLULU	3.0	1.00	HONOLULU	4.7	.98
		10	HONOLULU	3.0	.99	HONOLULU	4.7	.98
		12	HONOLULU	3.0	.97	HONOLULU	3.5	.97
		14	HONOLULU	3.0	.95	HONOLULU	3.0	.95
		16	HONOLULU	3.0	.89	HONOLULU	3.0	.92
		18	HONOLULU	4.7	.97	HONOLULU	6.6	.98
		20	HONOLULU	5.6	.94	HONOLULU	8.9	.98
		22	HONOLULU	6.6	.86	HONOLULU	11.3	.95
		24	HONOLULU	8.9	.96	HONOLULU	11.3	.97
JUN	200	2	SAN FRAN	4.7	.99	SAN FRAN	5.6	.97
		4	SAN FRAN	3.5	.99	SAN FRAN	4.7	.99
		6	SAN FRAN	3.5	1.00	SAN FRAN	4.7	1.00
		8	SAN FRAN	3.0	1.00	SAN FRAN	3.0	.99
		10	SAN FRAN	3.0	.99	SAN FRAN	3.0	.99
		12	SAN FRAN	3.0	.99	SAN FRAN	3.5	.99
		14	SAN FRAN	3.5	.99	SAN FRAN	4.7	.96
		16	SAN FRAN	3.0	.98	SAN FRAN	5.6	.91
		18	SAN FRAN	4.7	.91	SAN FRAN	6.6	.78
		20	SAN FRAN	4.7	.80	SAN FRAN	6.6	.65
		22	SAN FRAN	4.7	.82	SAN FRAN	6.6	.72
		24	SAN FRAN	4.7	.95	SAN FRAN	6.6	.84
	500	2	SAN FRAN	4.7	.99	SAN FRAN	6.6	.93
		4	SAN FRAN	5.6	1.00	SAN FRAN	5.6	.99
		6	SAN FRAN	3.5	1.00	SAN FRAN	4.7	1.00
		8	SAN FRAN	3.0	.99	SAN FRAN	3.5	1.00
		10	SAN FRAN	3.0	.99	SAN FRAN	4.7	1.00
		12	SAN FRAN	3.0	1.00	SAN FRAN	3.5	.99
		14	SAN FRAN	3.5	1.00	SAN FRAN	4.7	.98
		16	SAN FRAN	4.7	.99	SAN FRAN	5.6	.97
		18	SAN FRAN	5.6	.95	SAN FRAN	6.6	.94
		20	SAN FRAN	5.6	.90	SAN FRAN	6.6	.79
		22	SAN FRAN	5.6	.95	SAN FRAN	6.6	.84
		24	SAN FRAN	5.6	.98	SAN FRAN	6.6	.95
	1000	2	SAN FRAN	6.6	.99	SAN FRAN	8.9	[illegible]
		4	SAN FRAN	6.6	.99	SAN FRAN	8.9	.99
		6	SAN FRAN	6.6	1.00	SAN FRAN	6.6	1.00
		8	SAN FRAN	5.6	.98	SAN FRAN	4.7	.99
		10	SAN FRAN	4.7	.97	SAN FRAN	4.7	.99
		12	SAN FRAN	3.0	.96	SAN FRAN	3.5	.97
		14	SAN FRAN	5.6	.99	SAN FRAN	6.6	.98
		16	SAN FRAN	6.6	.97	SAN FRAN	8.9	.97
		18	SAN FRAN	8.9	.91	SAN FRAN	8.9	.87
		20	SAN FRAN	8.9	.80	SAN FRAN	11.3	.95
		22	SAN FRAN	8.9	.91	SAN FRAN	11.3	.90
		24	SAN FRAN	8.9	.96	SAN FRAN	8.9	.96

TABLE B-2. NORTH PACIFIC PATH (CONT.)

RELIABILITY TABLE HONOLULU TO SAN FRAN PATH

			SOLAR ACTIVITY LEVEL					
			SSN = 10			SSN = 110		
MONTH	DISTANCE	TIME	TERMINAL	FREQ	REL	TERMINAL	FREQ	REL
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
JUN	1500	2	SAN FRAN	11.3	.97	SAN FRAN	11.3	.98
		4	SAN FRAN	11.3	.98	SAN FRAN	13.3	.98
		6	SAN FRAN	8.9	.99	SAN FRAN	8.9	.99
		8	SAN FRAN	6.6	.95	SAN FRAN	8.9	.99
		10	SAN FRAN	6.6	.95	SAN FRAN	6.9	.99
		12	SAN FRAN	5.6	.94	SAN FRAN	6.6	.94
		14	SAN FRAN	6.6	.98	SAN FRAN	8.9	.98
		16	SAN FRAN	8.9	.97	SAN FRAN	11.3	.96
		18	SAN FRAN	11.3	.90	SAN FRAN	13.3	.91
		20	SAN FRAN	13.3	.84	SAN FRAN	13.3	.85
		22	SAN FRAN	11.3	.90	SAN FRAN	13.3	.90
		24	SAN FRAN	11.3	.96	SAN FRAN	11.3	.94
	2000	2	HONOLULU	18.0	.93	SAN FRAN	13.3	.93
		4	HONOLULU	18.0	.98	HONOLULU	18.0	.99
		6	SAN FRAN	11.3	.98	EITHER	13.3	.98
		8	HONOLULU	8.9	.97	EITHER	11.3	.98
		10	HONOLULU	8.9	.97	EITHER	11.3	.98
		12	HONOLULU	8.9	.97	HONOLULU	8.9	.97
		14	SAN FRAN	6.6	.93	HONOLULU	11.3	.93
		16	HONOLULU	8.9	.95	HONOLULU	11.3	.94
		18	HONOLULU	11.3	.90	HONOLULU	13.3	.95
		20	HONOLULU	13.3	.86	HONOLULU	18.0	.74
		22	SAN FRAN	13.3	.88	HONOLULU	18.0	.86
		24	SAN FRAN	11.3	.91	SAN FRAN	13.3	.95
	2500	2	HONOLULU	13.3	.97	HONOLULU	18.0	.95
		4	HONOLULU	13.3	.97	HONOLULU	18.0	.99
		6	HONOLULU	11.3	.99	HONOLULU	11.3	.99
		8	HONOLULU	8.9	.99	HONOLULU	8.9	.99
		10	HONOLULU	4.7	.98	HONOLULU	8.9	.99
		12	HONOLULU	5.6	.98	HONOLULU	6.6	.99
		14	HONOLULU	6.6	.97	HONOLULU	8.9	.97
		16	HONOLULU	6.6	.96	HONOLULU	8.9	.98
		18	HONOLULU	8.9	.93	HONOLULU	11.3	.98
		20	HONOLULU	11.3	.89	HONOLULU	13.3	.95
		22	HONOLULU	13.3	.92	HONOLULU	13.3	.77
		24	HONOLULU	13.3	.97	HONOLULU	15.0	[illegible]
	3000	2	HONOLULU	11.3	.99	HONOLULU	13.3	.98
		4	HONOLULU	8.9	.99	HONOLULU	8.9	.99
		6	HONOLULU	6.6	1.00	HONOLULU	8.9	1.00
		8	HONOLULU	4.7	.99	HONOLULU	5.6	1.00
		10	HONOLULU	3.5	.99	HONOLULU	5.6	1.00
		12	HONOLULU	3.5	.99	HONOLULU	5.6	1.00
		14	HONOLULU	3.5	.99	HONOLULU	5.6	.99
		16	HONOLULU	5.6	.98	HONOLULU	6.6	[illegible]
		18	HONOLULU	6.6	.95	HONOLULU	8.9	.99
		20	HONOLULU	8.9	.91	HONOLULU	11.3	.95
		22	HONOLULU	8.9	.91	HONOLULU	13.3	.95
		24	HONOLULU	11.3	.89	HONOLULU	13.3	.97

TABLE B-2. NORTH PACIFIC PATH (CONT.)

RELIABILITY TABLE HONOLULU TO SAN FRAN PATH

			SOLAR ACTIVITY LEVEL SSN = 10			SSN = 110		
MONTH (1)	DISTANCE (2)	TIME (3)	TERMINAL (4)	FREQ (5)	REL (6)	TERMINAL (7)	FREQ (8)	REL (9)
JUN	3500	2	HONOLULU	6.6	.99	HONOLULU	8.9	.98
		4	HONOLULU	5.6	1.00	HONOLULU	6.6	1.00
		6	HONOLULU	4.7	1.00	HONOLULU	4.7	1.00
		8	HONOLULU	3.0	1.00	HONOLULU	4.7	1.00
		10	HONOLULU	3.0	1.00	HONOLULU	4.7	1.00
		12	HONOLULU	3.0	1.00	HONOLULU	4.7	1.00
		14	HONOLULU	3.0	1.00	HONOLULU	4.7	1.00
		16	HONOLULU	3.0	.99	HONOLULU	5.6	.99
		18	HONOLULU	4.7	.98	HONOLULU	6.6	.98
		20	HONOLULU	5.6	.94	HONOLULU	8.9	.93
		22	HONOLULU	6.6	.89	HONOLULU	8.9	.77
		24	HONOLULU	8.9	.95	HONOLULU	11.3	.89
	3643	2	HONOLULU	6.6	.99	HONOLULU	8.9	.95
		4	HONOLULU	5.6	1.00	HONOLULU	6.6	.99
		6	HONOLULU	3.0	1.00	HONOLULU	4.7	.99
		8	HONOLULU	3.0	1.00	HONOLULU	3.0	.98
		10	HONOLULU	3.0	1.00	HONOLULU	3.5	.96
		12	HONOLULU	3.0	1.00	HONOLULU	3.0	.97
		14	HONOLULU	3.0	1.00	HONOLULU	3.5	.99
		16	HONOLULU	3.0	.99	HONOLULU	4.7	.99
		18	HONOLULU	4.7	.99	HONOLULU	5.6	.97
		20	HONOLULU	3.5	.89	HONOLULU	6.6	.95
		22	HONOLULU	6.6	.82	HONOLULU	8.9	.75
		24	HONOLULU	6.6	.92	HONOLULU	8.9	.83
SEP	200	2	SAN FRAN	3.5	.98	SAN FRAN	4.7	.97
		4	SAN FRAN	3.0	.99	SAN FRAN	3.5	.97
		6	SAN FRAN	3.0	.98	SAN FRAN	3.0	.94
		8	SAN FRAN	3.0	.96	SAN FRAN	3.0	.92
		10	SAN FRAN	3.0	.92	SAN FRAN	3.0	.90
		12	SAN FRAN	3.0	.93	SAN FRAN	3.0	.92
		14	SAN FRAN	3.0	.97	SAN FRAN	3.5	.92
		16	SAN FRAN	3.5	.95	SAN FRAN	5.6	.93
		18	SAN FRAN	4.7	.85	SAN FRAN	6.6	.83
		20	SAN FRAN	5.6	.68	SAN FRAN	8.9	.63
		22	SAN FRAN	5.6	.76	SAN FRAN	6.6	.75
		24	SAN FRAN	4.7	.94	SAN FRAN	6.6	.95
	500	2	SAN FRAN	4.7	.99	SAN FRAN	6.6	.96
		4	SAN FRAN	3.5	.99	SAN FRAN	4.7	.99
		6	SAN FRAN	3.0	.99	SAN FRAN	3.5	.99
		8	SAN FRAN	3.0	.98	SAN FRAN	3.5	.98
		10	SAN FRAN	3.0	.97	SAN FRAN	3.5	.94
		12	SAN FRAN	3.0	.97	SAN FRAN	3.5	.97
		14	SAN FRAN	3.0	.97	SAN FRAN	4.7	.95
		16	SAN FRAN	4.7	.98	SAN FRAN	6.6	.94
		18	SAN FRAN	5.6	.94	HONOLULU	13.3	.91
		20	SAN FRAN	6.6	.86	SAN FRAN	8.9	.75
		22	SAN FRAN	6.6	.89	SAN FRAN	8.9	.82
		24	SAN FRAN	4.7	.98	SAN FRAN	8.9	.93

TABLE B-2. NORTH PACIFIC PATH (CONT.)

RELIABILITY TABLE HONOLULU TO SAN FRAN PATH

			SOLAR ACTIVITY LEVEL SSN = 10			SSN = 110		
MONTH (1)	DISTANCE (2)	TIME (3)	TERMINAL (4)	FREQ (5)	REL (6)	TERMINAL (7)	FREQ (8)	REL (9)
SEP	1000	2	SAN FRAN	8.9	.98	SAN FRAN	11.3	.99
		4	SAN FRAN	6.6	.98	SAN FRAN	8.9	.99
		6	SAN FRAN	4.7	.97	SAN FRAN	6.6	.99
		8	SAN FRAN	4.7	.95	SAN FRAN	6.6	.98
		10	SAN FRAN	4.7	.94	SAN FRAN	5.6	.97
		12	SAN FRAN	3.9	.92	SAN FRAN	5.6	.96
		14	SAN FRAN	4.7	.97	SAN FRAN	6.6	.96
		16	SAN FRAN	6.6	.99	SAN FRAN	8.9	.96
		18	SAN FRAN	8.9	.95	SAN FRAN	11.3	.96
		20	SAN FRAN	8.9	.83	SAN FRAN	13.3	.89
		22	SAN FRAN	8.9	.91	SAN FRAN	11.3	.89
		24	SAN FRAN	8.9	.96	SAN FRAN	11.3	.96
	1500	2	SAN FRAN	11.3	.96	SAN FRAN	13.3	.97
		4	SAN FRAN	8.9	.96	SAN FRAN	11.3	.98
		6	SAN FRAN	6.6	.94	SAN FRAN	8.9	.98
		8	SAN FRAN	5.6	.90	SAN FRAN	8.9	.96
		10	SAN FRAN	5.6	.89	SAN FRAN	8.9	.95
		12	SAN FRAN	5.6	.88	SAN FRAN	6.6	.93
		14	SAN FRAN	5.6	.93	SAN FRAN	8.9	.95
		16	SAN FRAN	8.9	.97	SAN FRAN	11.3	.97
		18	SAN FRAN	11.3	.89	HONOLULU	18.0	.70
		20	SAN FRAN	11.3	.93	SAN FRAN	13.3	.75
		22	SAN FRAN	11.3	.82	SAN FRAN	13.3	.80
		24	SAN FRAN	11.3	.96	SAN FRAN	13.3	.96
	2000	2	HONOLULU	18.0	.96	SAN FRAN	18.0	.94
		4	HONOLULU	13.3	.96	HONOLULU	18.0	.99
		6	HONOLULU	8.9	.94	HONOLULU	18.0	.99
		8	HONOLULU	6.6	.90	HONOLULU	8.9	.98
		10	HONOLULU	5.6	.86	HONOLULU	8.9	.96
		12	HONOLULU	5.6	.85	EITHER	8.9	.92
		14	HONOLULU	6.6	.82	HONOLULU	8.9	.92
		16	SAN FRAN	8.9	.90	HONOLULU	13.3	.93
		18	HONOLULU	11.3	.93	HONOLULU	18.0	.90
		20	HONOLULU	13.3	.90	HONOLULU	18.0	.87
		22	SAN FRAN	13.3	.77	SAN FRAN	18.0	.79
		24	SAN FRAN	13.3	.90	SAN FRAN	18.0	.87
	2500	2	HONOLULU	18.0	.99	HONOLULU	18.0	.98
		4	HONOLULU	13.3	.99	HONOLULU	18.0	1.00
		6	HONOLULU	5.6	.97	HONOLULU	8.9	.99
		8	HONOLULU	5.6	.95	HONOLULU	8.9	.99
		10	HONOLULU	4.7	.93	HONOLULU	8.9	.99
		12	HONOLULU	6.6	.94	HONOLULU	8.9	.98
		14	HONOLULU	4.7	.90	HONOLULU	5.9	.94
		16	HONOLULU	6.6	.96	HONOLULU	11.3	.97
		18	HONOLULU	8.9	.97	HONOLULU	18.0	.94
		20	HONOLULU	11.3	.93	HONOLULU	18.0	.95
		22	HONOLULU	13.3	.94	HONOLULU	18.0	.94
		24	HONOLULU	13.3	.95	HONOLULU	18.0	.96

TABLE B-2. NORTH PACIFIC PATH (CONT.)

RELIABILITY TABLE HONOLULU TO SAN FRAN PATH

			SOLAR ACTIVITY LEVEL SSN = 10			SSN = 110		
MONTH	DISTANCE	TIME	TERMINAL	FREQ	REL	TERMINAL	FREQ	REL
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
SEP	3000	2	HONOLULU	11.3	.99	HONOLULU	18.0	1.00
		4	HONOLULU	11.3	1.00	HONOLULU	11.3	1.00
		6	HONOLULU	4.7	.99	HONOLULU	8.9	1.00
		8	HONOLULU	3.0	.94	HONOLULU	8.9	1.00
		10	HONOLULU	3.0	.97	HONOLULU	8.9	1.00
		12	HONOLULU	3.5	.96	HONOLULU	6.6	.99
		14	HONOLULU	3.0	.95	HONOLULU	4.7	.96
		16	HONOLULU	4.7	.96	HONOLULU	5.6	.95
		18	HONOLULU	6.6	.98	HONOLULU	13.3	.99
		20	HONOLULU	8.9	.96	HONOLULU	13.3	.97
		22	HONOLULU	11.3	.98	HONOLULU	13.3	.84
		24	HONOLULU	11.3	.98	HONOLULU	13.3	.89
	3500	2	HONOLULU	8.9	1.00	HONOLULU	11.3	.99
		4	HONOLULU	5.6	1.00	HONOLULU	8.9	1.00
		6	HONOLULU	3.0	1.00	HONOLULU	5.6	1.00
		8	HONOLULU	3.0	.99	HONOLULU	5.6	.99
		10	HONOLULU	3.0	.98	HONOLULU	4.7	.97
		12	HONOLULU	3.0	.98	HONOLULU	4.7	.95
		14	HONOLULU	3.0	.96	HONOLULU	3.5	.98
		16	HONOLULU	3.0	.96	HONOLULU	4.7	.97
		18	HONOLULU	4.7	.99	HONOLULU	8.9	.99
		20	HONOLULU	5.6	.97	HONOLULU	8.9	.94
		22	HONOLULU	8.9	.88	HONOLULU	11.3	.89
		24	HONOLULU	8.9	.98	HONOLULU	11.3	.94
	3643	2	HONOLULU	6.6	.99	HONOLULU	8.9	.98
		4	HONOLULU	3.5	.99	HONOLULU	5.6	.99
		6	HONOLULU	3.0	1.00	HONOLULU	4.7	.99
		8	HONOLULU	3.0	.99	HONOLULU	4.7	.97
		10	HONOLULU	3.0	.98	HONOLULU	4.7	.96
		12	HONOLULU	3.0	.98	HONOLULU	4.7	.95
		14	HONOLULU	3.0	.93	HONOLULU	3.0	.93
		16	HONOLULU	3.0	.95	HONOLULU	3.5	.92
		18	HONOLULU	4.7	.98	HONOLULU	6.6	.97
		20	HONOLULU	5.6	.93	HONOLULU	8.9	.94
		22	HONOLULU	6.6	.93	HONOLULU	11.3	.84
		24	HONOLULU	6.6	.93	HONOLULU	11.3	.95
DEC	200	2	SAN FRAN	3.0	1.00	SAN FRAN	3.5	.99
		4	SAN FRAN	3.0	.92	SAN FRAN	3.0	.99
		6	SAN FRAN	3.0	.95	SAN FRAN	3.0	.99
		8	SAN FRAN	3.0	.98	SAN FRAN	3.0	.99
		10	SAN FRAN	3.0	.99	SAN FRAN	3.0	.96
		12	SAN FRAN	3.0	.97	SAN FRAN	3.0	.97
		14	SAN FRAN	3.0	.89	SAN FRAN	3.0	.96
		16	SAN FRAN	3.5	.99	SAN FRAN	4.7	.99
		18	SAN FRAN	4.7	.98	SAN FRAN	6.6	.99
		20	SAN FRAN	5.6	.97	SAN FRAN	8.9	.93
		22	SAN FRAN	5.6	.98	SAN FRAN	8.9	.99
		24	SAN FRAN	3.5	.99	SAN FRAN	5.6	.99

TABLE B-2. NORTH PACIFIC PATH (CONT.)

RELIABILITY TABLE HONOLULU TO SAN FRAN PATH

			SOLAR ACTIVITY LEVEL SSN = 10			SSN = 110		
MONTH	DISTANCE	TIME	TERMINAL	FREQ	REL	TERMINAL	FREQ	REL
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
DEC	500	2	SAN FRAN	3.0	1.00	SAN FRAN	4.7	.99
		4	SAN FRAN	3.0	.99	SAN FRAN	3.5	1.00
		6	SAN FRAN	3.0	.98	SAN FRAN	3.5	1.00
		8	SAN FRAN	3.0	.99	SAN FRAN	3.5	1.00
		10	SAN FRAN	3.0	1.00	SAN FRAN	3.5	1.00
		12	SAN FRAN	3.0	.99	SAN FRAN	3.0	.99
		14	SAN FRAN	3.0	.98	SAN FRAN	3.0	.99
		16	SAN FRAN	3.0	.99	SAN FRAN	6.6	.98
		18	SAN FRAN	6.6	.99	SAN FRAN	8.9	.98
		20	SAN FRAN	6.6	.96	SAN FRAN	11.3	.97
		22	SAN FRAN	6.6	.98	SAN FRAN	11.3	.98
		24	SAN FRAN	5.6	1.00	SAN FRAN	8.9	.99
	1000	2	SAN FRAN	4.7	.99	SAN FRAN	11.3	1.00
		4	SAN FRAN	3.0	.98	SAN FRAN	5.6	.99
		6	SAN FRAN	3.0	.98	SAN FRAN	4.7	.99
		8	SAN FRAN	3.0	.98	SAN FRAN	4.7	.99
		10	SAN FRAN	3.5	.99	SAN FRAN	4.7	.99
		12	SAN FRAN	3.5	.98	SAN FRAN	4.7	.98
		14	SAN FRAN	3.5	.98	SAN FRAN	3.0	.97
		16	SAN FRAN	6.6	.98	SAN FRAN	8.9	.98
		18	SAN FRAN	8.9	.97	SAN FRAN	13.3	.95
		20	SAN FRAN	11.3	.97	SAN FRAN	13.3	.90
		22	SAN FRAN	11.3	.98	SAN FRAN	13.3	.92
		24	SAN FRAN	8.9	.99	SAN FRAN	11.3	.99
	1500	2	SAN FRAN	8.9	.98	SAN FRAN	13.3	.99
		4	SAN FRAN	4.7	.96	SAN FRAN	11.3	.99
		6	SAN FRAN	4.7	.95	SAN FRAN	6.6	.97
		8	SAN FRAN	4.7	.95	SAN FRAN	6.6	.97
		10	SAN FRAN	4.7	.96	SAN FRAN	6.6	.97
		12	SAN FRAN	5.6	.95	SAN FRAN	6.6	.96
		14	SAN FRAN	4.7	.93	SAN FRAN	5.6	.93
		16	SAN FRAN	8.9	.96	SAN FRAN	11.3	.96
		18	SAN FRAN	13.3	.96	SAN FRAN	18.0	.93
		20	SAN FRAN	13.3	.96	SAN FRAN	18.0	.89
		22	SAN FRAN	13.3	.90	SAN FRAN	18.0	.91
		24	SAN FRAN	13.3	.98	SAN FRAN	18.0	.98
	2000	2	HONOLULU	18.0	.97	SAN FRAN	18.0	.97
		4	HONOLULU	8.9	.94	HONOLULU	18.0	.99
		6	SAN FRAN	5.6	.91	HONOLULU	13.3	.95
		8	SAN FRAN	5.6	.90	HONOLULU	11.3	.97
		10	SAN FRAN	5.6	.89	HONOLULU	8.9	.95
		12	HONOLULU	5.6	.90	HONOLULU	6.6	.91
		14	HONOLULU	5.6	.86	HONOLULU	6.6	.89
		16	SAN FRAN	11.3	.91	SAN FRAN	13.3	.91
		18	HONOLULU	13.3	.91	HONOLULU	18.0	.89
		20	HONOLULU	18.0	.90	EITHER	18.0	.94
		22	HONOLULU	18.0	.86	HONOLULU	18.0	.75
		24	HONOLULU	18.0	.91	SAN FRAN	18.0	.91

TABLE B-2. NORTH PACIFIC PATH (CONT.)

RELIABILITY TABLE HONOLULU TO SAN FRAN PATH

			SOLAR ACTIVITY LEVEL SSN = 10			SSN = 110		
MONTH	DISTANCE	TIME	TERMINAL	FREQ	REL	TERMINAL	FREQ	REL
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
DEC	2500	2	HONOLULU	13.3	.97	HONOLULU	18.0	.99
		4	HONOLULU	8.9	.98	HONOLULU	11.3	.99
		6	HONOLULU	5.6	.91	HONOLULU	8.9	.99
		8	HONOLULU	4.7	.90	HONOLULU	11.3	.99
		10	HONOLULU	3.5	.97	HONOLULU	5.6	.96
		12	HONOLULU	4.7	.94	HONOLULU	5.6	.96
		14	HONOLULU	4.7	.89	HONOLULU	4.7	.95
		16	HONOLULU	4.7	.98	HONOLULU	5.6	.94
		18	HONOLULU	11.3	.97	HONOLULU	18.0	.96
		20	HONOLULU	13.3	.96	HONOLULU	18.0	.89
		22	HONOLULU	13.3	.95	HONOLULU	18.0	.94
		24	HONOLULU	18.0	.98	HONOLULU	18.0	.94
	3000	2	HONOLULU	8.9	.99	HONOLULU	11.3	.99
		4	HONOLULU	5.6	.99	HONOLULU	8.9	1.00
		6	HONOLULU	3.5	.97	HONOLULU	6.6	1.00
		8	HONOLULU	3.0	.95	HONOLULU	5.6	.99
		10	HONOLULU	3.0	.94	HONOLULU	4.7	.99
		12	HONOLULU	3.5	.98	HONOLULU	5.6	.99
		14	HONOLULU	3.0	.93	HONOLULU	3.0	.98
		16	HONOLULU	3.0	.95	HONOLULU	3.5	.97
		18	HONOLULU	8.9	.99	HONOLULU	13.3	.97
		20	HONOLULU	13.3	.99	HONOLULU	18.0	.98
		22	HONOLULU	11.3	.98	HONOLULU	13.3	.92
		24	HONOLULU	11.3	.96	HONOLULU	13.3	.91
	3500	2	HONOLULU	6.6	1.00	HONOLULU	8.9	.99
		4	HONOLULU	3.5	1.00	HONOLULU	4.7	.99
		6	HONOLULU	3.0	1.00	HONOLULU	5.6	1.00
		8	HONOLULU	3.0	.98	HONOLULU	4.7	.98
		10	HONOLULU	3.0	.93	HONOLULU	3.0	.99
		12	HONOLULU	3.0	.99	HONOLULU	3.0	.99
		14	HONOLULU	3.0	.93	HONOLULU	3.0	.99
		16	HONOLULU	3.0	.91	HONOLULU	3.0	.94
		18	HONOLULU	5.6	1.00	HONOLULU	8.9	.98
		20	HONOLULU	8.9	.99	HONOLULU	11.3	.98
		22	HONOLULU	8.9	.93	HONOLULU	11.3	.92
		24	HONOLULU	8.9	.99	HONOLULU	11.3	.96
	3643	2	HONOLULU	5.6	1.00	HONOLULU	8.9	.99
		4	HONOLULU	3.0	1.00	HONOLULU	4.7	.99
		6	HONOLULU	3.0	1.00	HONOLULU	3.0	.99
		8	HONOLULU	3.0	.97	HONOLULU	3.0	.97
		10	HONOLULU	3.0	.98	HONOLULU	3.0	.96
		12	HONOLULU	3.0	.98	HONOLULU	3.0	.95
		14	HONOLULU	3.0	.89	HONOLULU	3.0	.96
		16	HONOLULU	3.0	.94	HONOLULU	3.0	.96
		18	HONOLULU	3.5	.97	HONOLULU	6.6	.99
		20	HONOLULU	6.6	.98	HONOLULU	8.9	.99
		22	HONOLULU	6.6	.90	HONOLULU	8.9	.92
		24	HONOLULU	6.6	.96	HONOLULU	8.9	.95

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